3.1

MARINE LAYER STRATUS STUDY

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11.0 Introduction.

This study looks at the Vandenberg AFB weather forecaster methodologies and validates them. The forecast models were also studied to see which one performed the best focusing on the key features used to forecast the marine layer stratus for aviation forecasts. The study also reviews three distinct weather events that occurred at Vandenberg AFB during the collection period; a southerly surge, an extreme maximum temperature event, and drizzle occurring with clouds less than 2,000 feet thick.

The author follows the assumption that the best description of the marine layer development process at Vandenberg Air Force Base is Leipper's[1] four phases of the marine layer fog/stratus, which are as follows:

1st Phase Offshore Breeze – strengthen the subsidence inversion, providing drier air aloft

2nd Phase Marine layer inversion established up to 200 meters (650 feet)

3rd Phase Marine Layer inversion is establish between 200-400 meters (650-1,300 feet)

4th Phase Lifting of the marine layer

The author also presumes the reader is familiar with the weather feature known as the southerly surge as describe by Peter Felsch[2] in his article *Stratus Surge Prediction along the Central California Coast*.

The study covers three major areas. The first section describes the actual marine layer conditions from 16 August 2005 to 17 September 2005. The second section describes different weather features that affect the marine layer. The third section discusses how well the models handle the weather features outlined by the previous two sections.

The collection methods used in this study:

- Data collection period was 16 Aug 04 – 17 Sep 04.

- The normal daily synoptic Upper Air Sounding (00Z and 12Z) were used for during the entire study period plus two additional Upper Air Soundings (15Z and 18Z Mon-Fri) only requiring the data up to 60,000 feet.

- Printed and saved model charts (MM5, mesoscale ETA, AVN, LAPS).

- Collected Vandenberg (KVAD) Airfield ASOS observations.

- Collected 12Z and 00Z from two Buoys for SST (46023 and 40611).

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[1] Leipper, Dale F., June 1994, Fog Forecasting Objectively in the California Coastal Area Using LIBS, 1995 American Meteorological Society, Weather and Forecasting, Vol 10, No 2, pages 741-761

[2] Felsch, Peter, December 1990: Stratus Surge Prediction along the Central California Coast, NOAA Technical Memorandum NWS WR-209.[2]

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2.0 Marine Layer Conditions.

2.1 Visibility versus Ceilings Heights. At Vandenberg AFB terrain is a key player in marine layer and fog behavior. If conditions set up for the marine layer to develop, low-level convergence and divergence play an important role in the severity of the event. If the surface low-level wind flow is divergence then low visibilities develop within the marine layer (Vertical Visibility conditions).

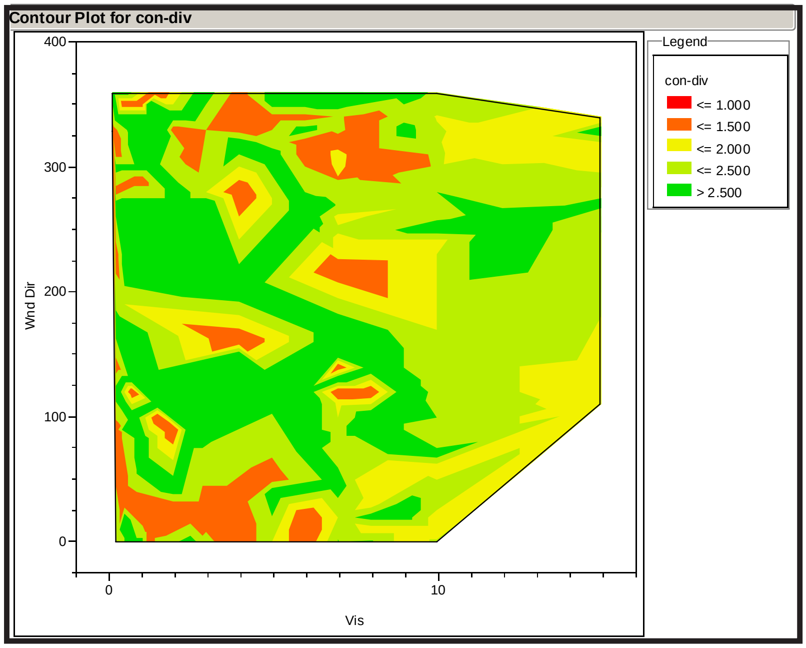

Figure 1. Visibility Versus Wind Direction Versus Convergence and Divergence without Southerly Surge.

Figures 1 and 2, which show visibility versus wind direction versus convergence and divergence, indicate a correlation exists between convergence, divergence, wind direction and low visibility. When the wind direction is from 010º to 100º or from 300º to 360º, visibility less than 3 statute miles occurs most frequently with surface convergence. When the wind direction is from 100º to 290º, visibility less than 3 statute miles occurs most frequently with surface divergence. On the following figures, red depicts surface convergence while green is assigned to surface divergence.

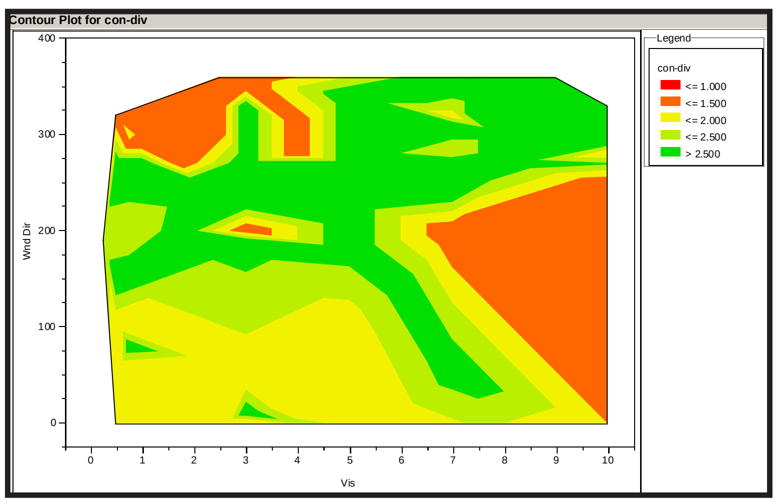

Figure 2. Visibility Versus Wind Direction Versus Convergence and Divergence during a Southerly Surge.

During a southerly surge event, the visibility versus wind direction versus convergence and divergence shown in Figure 2 indicates a different correlation exists between the convergence, divergence, wind direction and low visibility. When the wind direction is from northwest to north, visibility less than 3 statute miles occurs most frequently under convergence conditions. Visibility less than 3 statute miles occurs most frequently under neutral conditions when the wind direction is from north to southeast. When the wind direction is from southeast to west, visibility less than 3 statute miles occurs most frequently under either neutral or divergence conditions.

Figures 3 and 4 show a correlation exists between convergence, divergence, wind direction and ceiling heights. During marine layer stratus events, ceiling heights below 500 feet most often occurred with surface convergence when the wind direction was north to northeast. Ceilings from 500 feet to 1,000 feet occurred with surface convergence when the wind direction was from south to north. Ceilings 1,000 feet to 1,500 feet occurred with surface convergence when the wind direction was from southwest to northwest. Ceilings 1,500 feet to 2,400 feet occurred with surface convergence when the wind direction was from north to east. Ceilings above 2,500 feet occurred with surface convergence when the wind direction was from south to southwest.

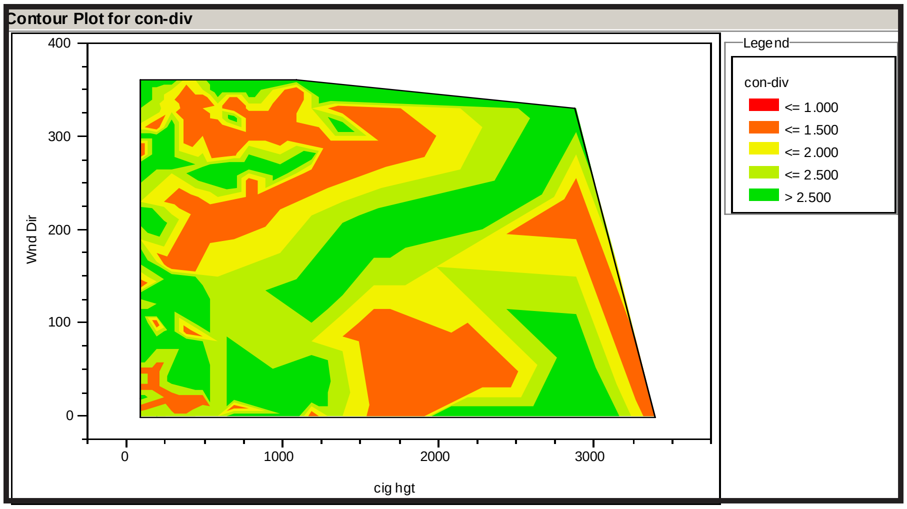

Figure 3. Cloud Heights Versus Wind Direction Versus Convergence and Divergence without a Southerly Surge.

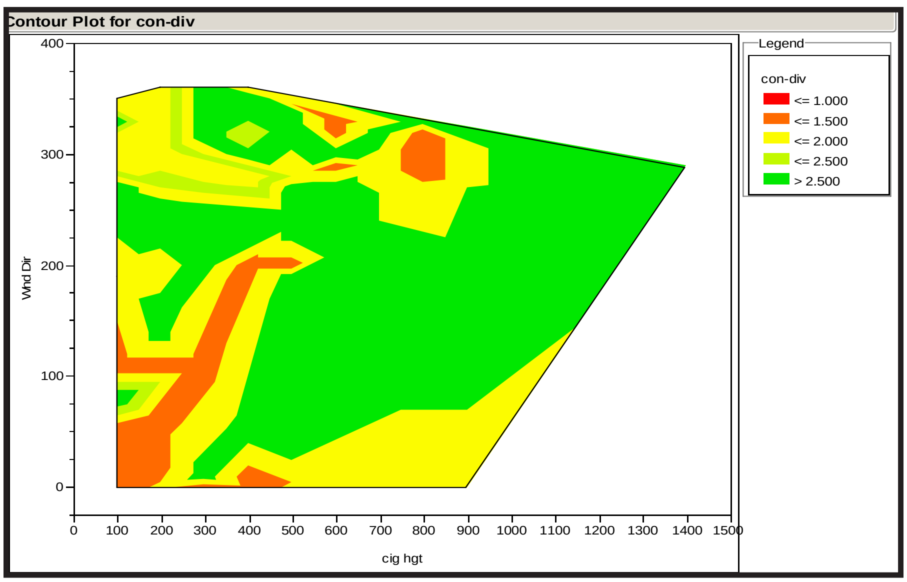

Figure 4. Cloud Heights Versus Wind Direction Versus Convergence and Divergence during a Southerly Surge.

Ceiling heights below 500 feet occurred with surface divergence when the wind direction was from northeast to west. Vertical visibility conditions are often associated with ceilings below 300 feet. Ceilings between 500 feet to 1000 feet occurred with surface divergence when the wind direction was from north to east. Ceilings 1,000 feet to 1,500 feet occurred with surface convergence when the wind direction was from east to southwest. Ceilings between 1,500 feet and 2,400 feet occurred with surface divergence when the wind direction was from southwest to north. Ceilings above 2,400 feet occurred with surface divergence when the wind direction was from north to east.

During southerly surge events the relationship between wind direction, convergence, divergence and ceiling heights shifted, becoming simpler. Ceilings heights below 200 feet occured with surface convergence when the wind direction was from north to northeast and from east to southeast. Ceilings heights below 500 feet occurred with surface convergence when the wind direction was from north and east to southwest. Ceilings 500 feet to 900 feet occured with surface convergence when the wind direction was from west to north. Ceilings below 200 feet occurred with surface divergence when the wind direction was from southwest to west. Ceilings between 200 feet and 500 feet occurred with surface divergence when the wind direction was from southwest to north. Ceilings between 500 feet and 900 feet occurred with surface divergence when the wind direction was from northeast to west. Ceilings above 900 feet occurred with surface divergence from southeast to north. Ceiling heights below 200 feet occurred with surface neutral when wind directions were from northeast to east, south to southwest and west to north.

There is a strong correlation between the height of the marine layer inversion and the restriction to visibility. There were only two observations out of 169 where visibility was lower than 3 statute miles and the ceilings where equal to or greater than 500 feet.

Figure 5 shows that visibilities 3 statute miles or less did not occur with wind speeds greater than 7 knots.

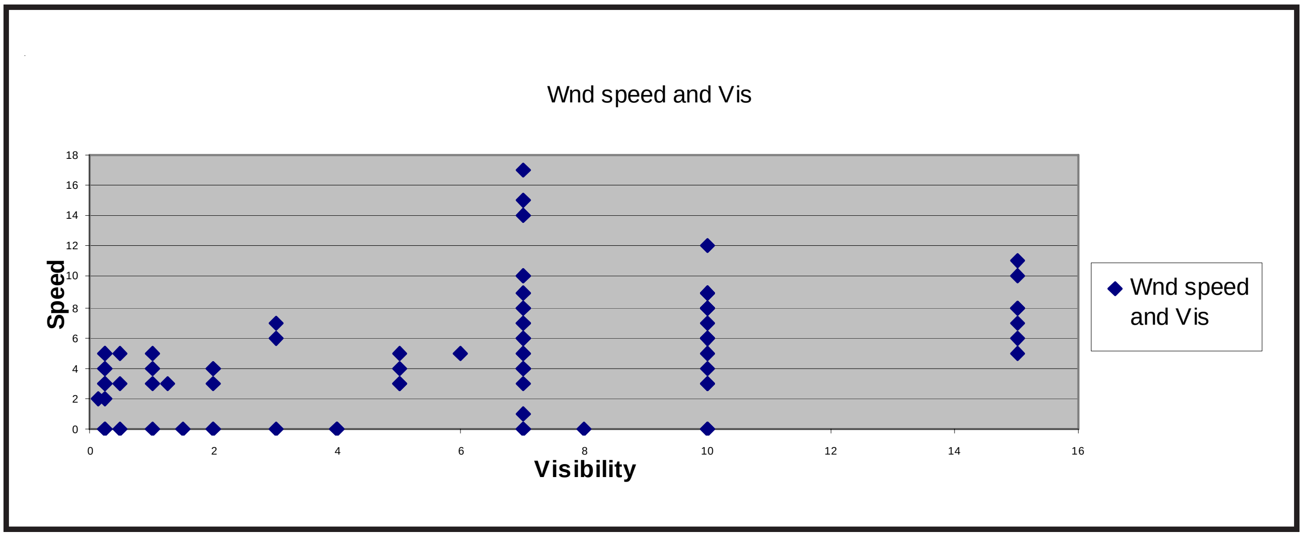

Figure 5. Wind Speed Versus Visibility.

2.2 Wind Direction.

There appears to be three dominate wind directions at Vandenberg AFB during the summer: land breeze (southeasterly), sea breeze (northwesterly) and gradient flow (northeasterly). See Figure 6 for wind direction versus 925-mb temperatures.

The surface gradient wind flow for Vandenberg AFB during the summer is controlled by the interaction of the thermal trough in the central California valley and the position of the Pacific ridge (see Figure 7). If the thermal trough is the dominant feature, the flow will be northeasterly. If the Pacific ridge is the dominant feature, the surface gradient flow will be northwesterly to northerly.

Let's go over some of the basics about the land-sea breeze interaction. Sea breezes blow perpendicular to the coastline from sea to land, while the reverse happens with the land breeze. Sea breeze begins to develop 3 to 4 hours after sunrise with peak gusts occurring in the afternoon. The best conditions for land and sea breezes to develop are weak surface pressure gradients and clear skies, which allow for strong heating and radiational cooling. The land breeze generally develops shortly after midnight and peaks near sunrise.

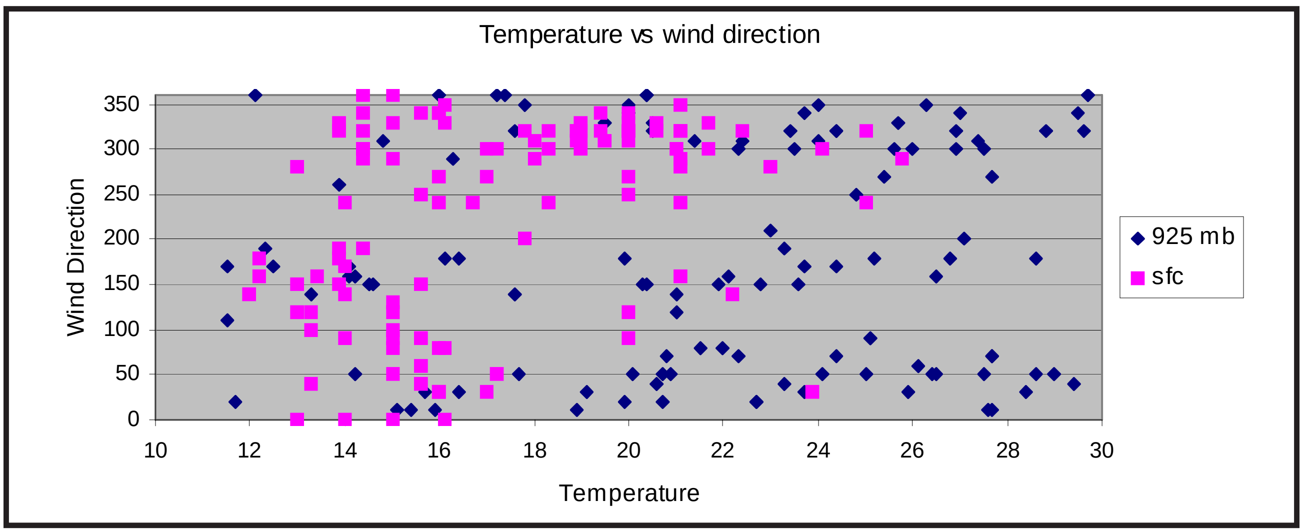

Figure 6. Wind Direction Versus Surface and 925-mb Temperatures.

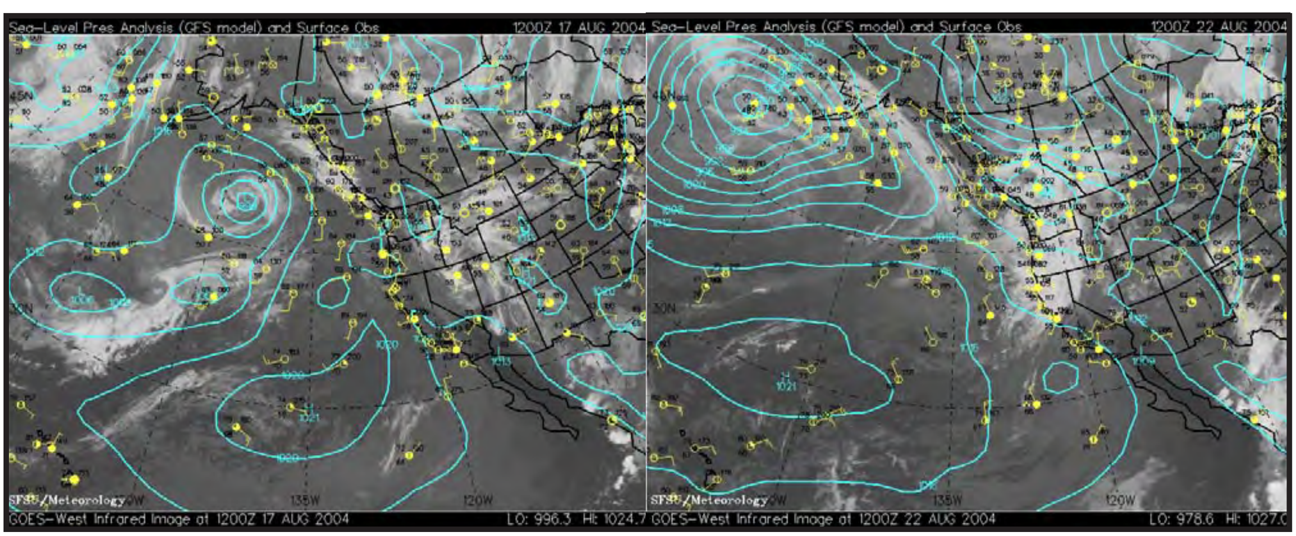

Figure 7. Surface Circulation Overlaid on Satellite Images for 17 and 22 Aug 05.

As you can see in Figure 8, when the land and sea temperatures are the same, the wind direction can be from any direction. When sea surface temperature (SST) are greater than 2^{o}F above the surface temperature, winds are mainly from the northeast to southeast direction (except for days when a strong offshore wind develops and the direction remains out of east to southeast). When surface temperatures are between 1^{o}F above to 5^{o} F below the sea surface temperature, then the wind direction is based on the surface gradient flow.

Figure 9 shows the sea breeze as the dominant feature after 18Z. Winds between south and west were associated with southerly surges. Sunrise during this study was from 1323Z –1346Z.

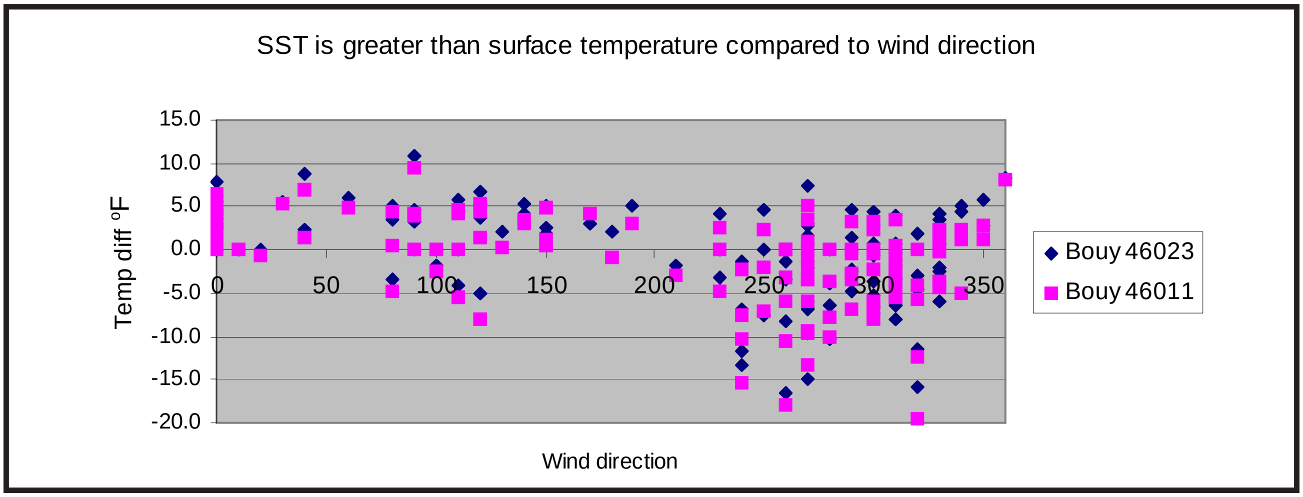

Figure 8. Difference between the Sea Surface and Land Surface Temperatures Compared to Wind Direction.

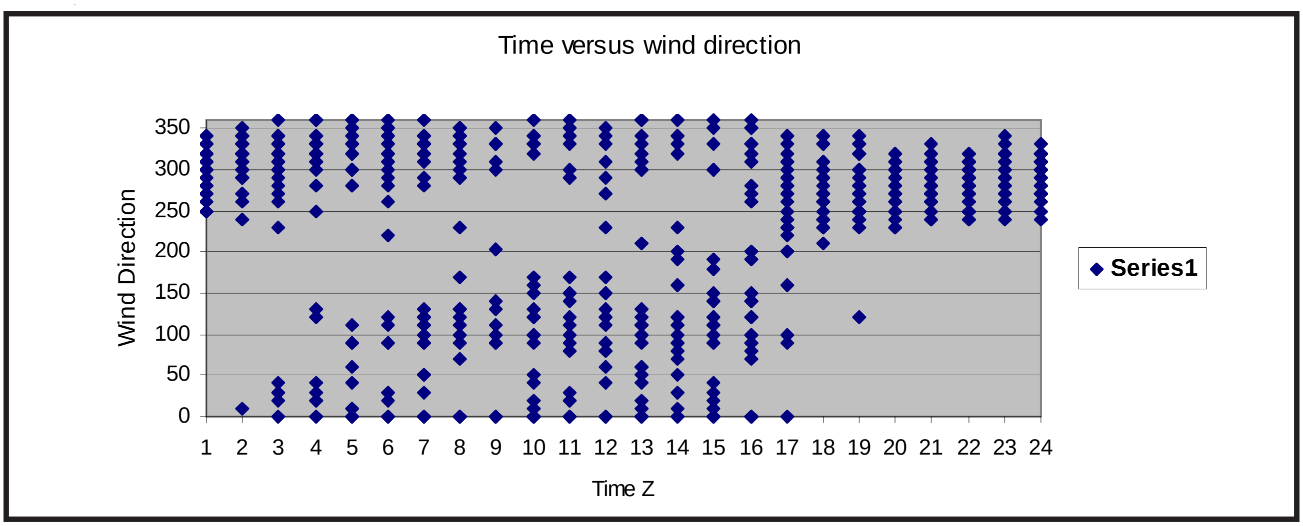

Figure 9. Time of Day Versus the Wind Direction.

Figure 10 indicates the largest SST and land temperature difference occur around 12Z and begins to decrease by 15Z, which correlates the establishment of a land breeze.

During offshore wind events the surface temperature rapidly climbs during the morning hours reaching the maximum temperature by 18Z (during this study the maximum surface temperature reached was 30ºC). Even with weak-to-moderate offshore gradient flow, the sea breeze eventually predominates and progresses past the airfield (See Figure 9).

Figure 11 looks at the SST and land temperature difference versus wind direction and wind speed. The largest difference occurred when the wind speeds were less than 5 knots with northerly to southeasterly wind directions.

The dynamics that occur during sea and land breezes must be incorporated into the forecast process at Vandenberg AFB. In addition, forecasters rely on the mesoscale models, so initialization and verification remain a very important part of the process of recognizing slight shifts in the weather pattern.

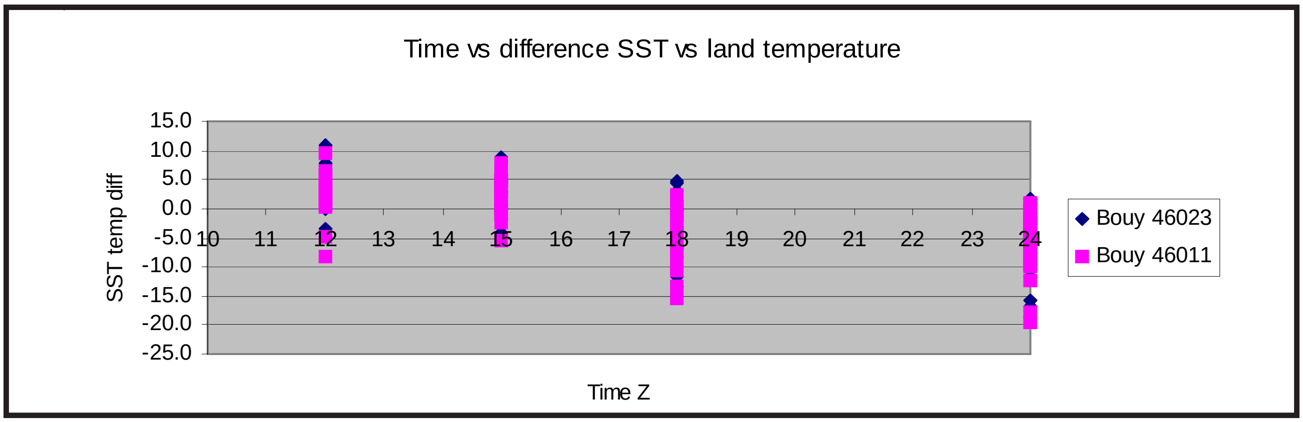

Figure 10. Difference between the Sea Surface and Land Surface Temperatures Compared to the Time of Day.

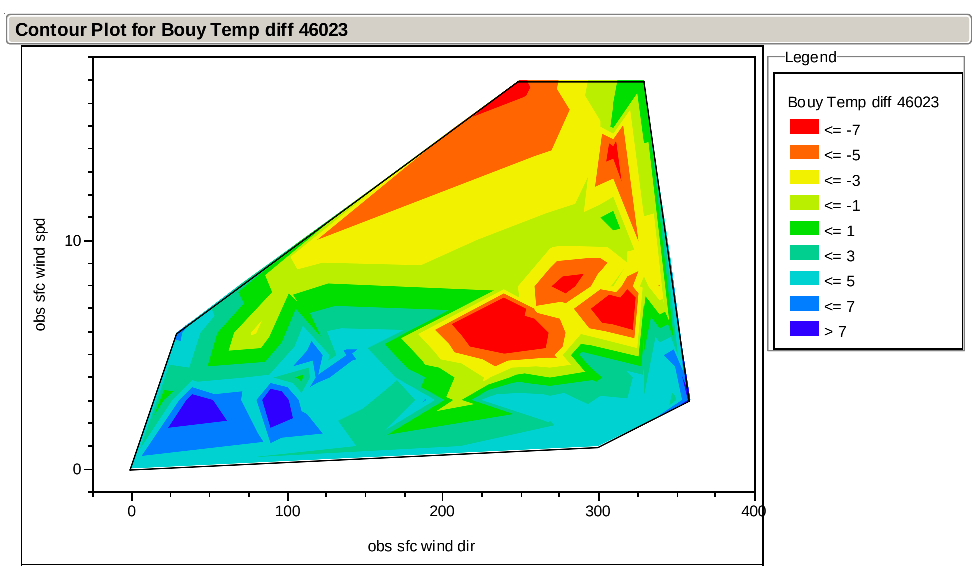

Figure 11. Difference between the Sea Surface and Land Surface Temperatures at Buoy 46023 Compared to the Surface Wind Direction.

2.3 Temperatures.

Surface temperature is also an important factor in the marine layer forecasting process.

Minimum Surface Temperature.

Correctly forecasting minimum surface temperature is the key to forecasting the wind direction. Figure 12 compares dewpoint temperatures at different times the previous day to next day's minimum temperature. When one looks solely at dewpoint temperature no trends were indicated on the chart; however, when wind direction is added, a pattern did emerge (see Figure 13). If the observed wind direction was west to northeast, the 19Z dewpoint temperature was a good indicator for minimum temperature. If the observed wind direction was east to southeast, then use the 23Z dewpoint temperature minus 6°F to forecast the minimum surface temperature. The only two exceptions were a result of dry adiabatic heating and strong offshore winds associated with a Great Basin high.

The general forecasting rule of using the surface dewpoint temperature that is associated with the surface maximum temperature in the afternoon to forecast the next morning low needs to be adjusted for Vandenberg AFB. This rule works only as long as the airmass has not been modified. Normally the maximum temperature occurs between 20Z to 21Z with an exception occurring during an offshore wind event.

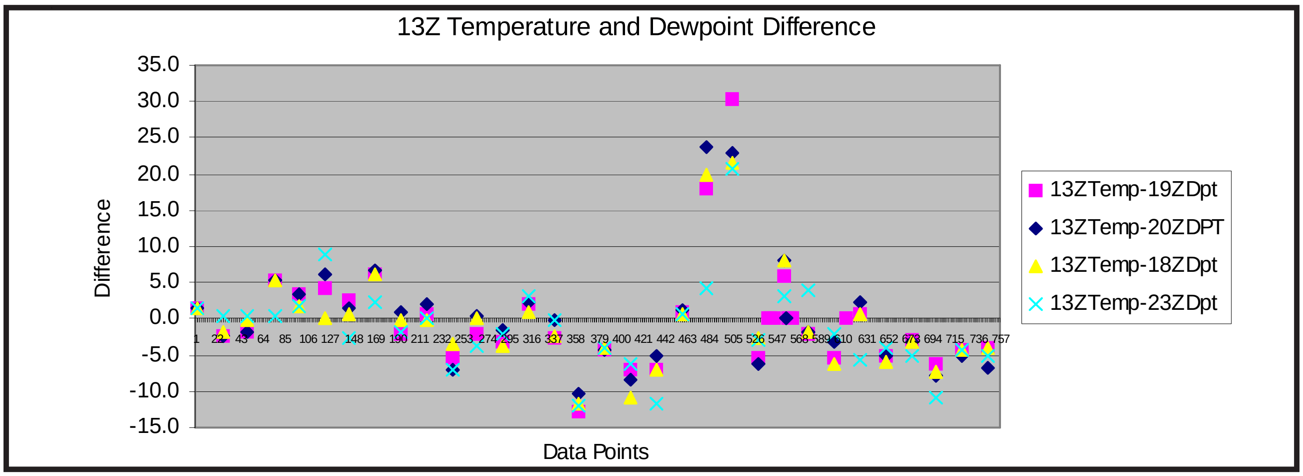

Figure 12. The Difference between the Previous Day Afternoon Dewpoint Temperature and Next Day's 13Z Dry Bulb Temperature.

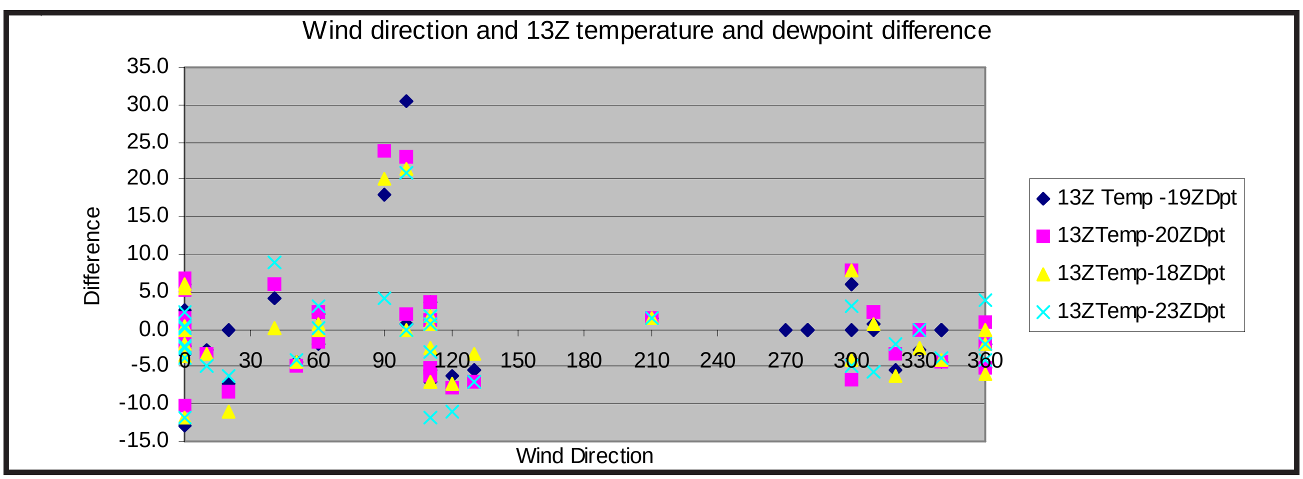

Figure 13. The Difference between the Previous Day Afternoon Dewpoint Temperature and Next Day's 13Z Dry Bulb Temperature with the Addition of Wind Direction.

Figure 14 indicates there are actually three small dips (04Z, 08Z and 13Z) for lower temperatures during the night. There are two higher temperature peaks occurring at 17Z and 21Z. Later in this study it will be shown that the marine layer undergoes a cyclic pattern of increasing and decreasing ceilings heights.

3.0 Weather Features that Affect the Marine Layer.

3.1 Cloud Thickness

The following diagrams and charts show that a correlation exists between the marine layer thickness, 500-mb height advection and 500-mb temperature advection.

It appears the marine layer depth becomes the greatest when the 500-mb heights are increasing (+10m to +20m) and weak or no 500-mb warm air advection (0°C to +1°C) occurs within the past three hours (see Figure 15). This situation normally occurs when either the atmosphere is stabilizing or the 500-mb contour and thermal ridges are approaching. The increasing cloud thickness can occur in two ways. First, the cloud tops remain the same while ceiling bases lower. Secondly, the ceiling base remains the same while the cloud top increases.

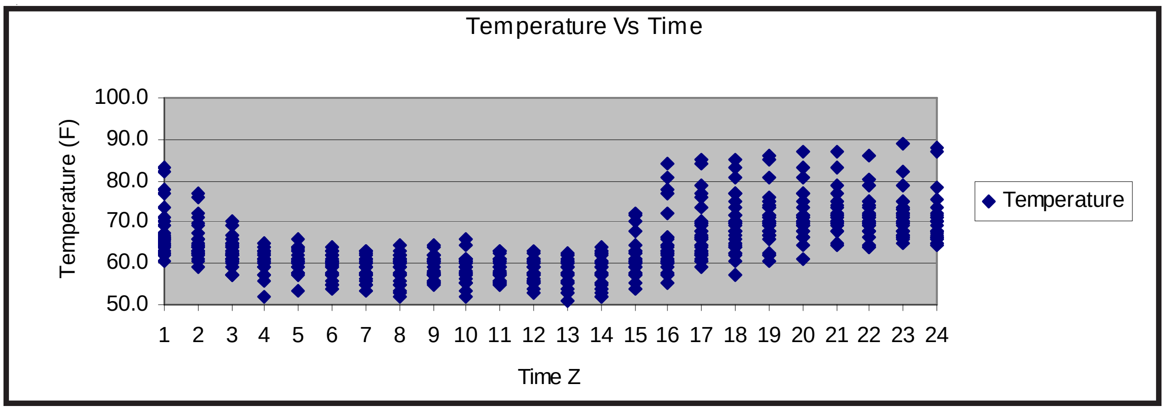

Figure 14. Temperature Versus Time (Z) of Day.

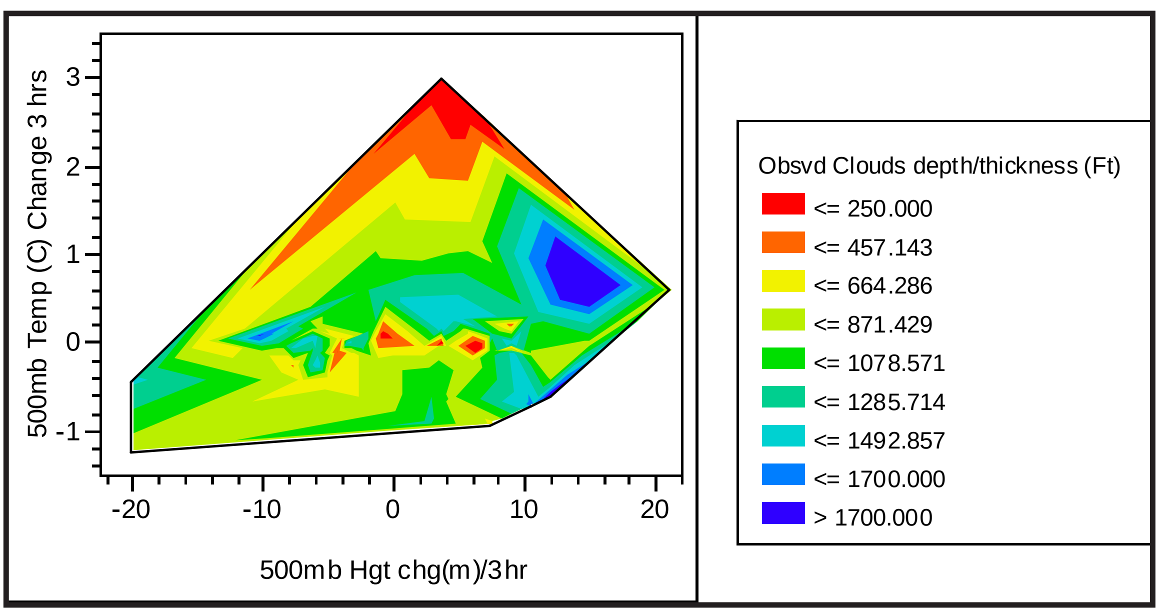

Figure 15. 500-mb Temperature Change/500-mb Height Change/Cloud thickness.

During the morning hours, the combined effect of 500-mb cold air advection (-0.5ºC to -1.2ºC) and 500-mb heights change (-5m to +12m) within the past 3 hours increases cloud thickness and oppose the normal solar insulation burn off (see Figure 16). In other words, if at 12Z the clouds are 800 feet thick, then by 15Z the cloud depth will increase to 1200 feet. This affects the burn-off time by delaying scattered conditions for another 1 to 2 hours.

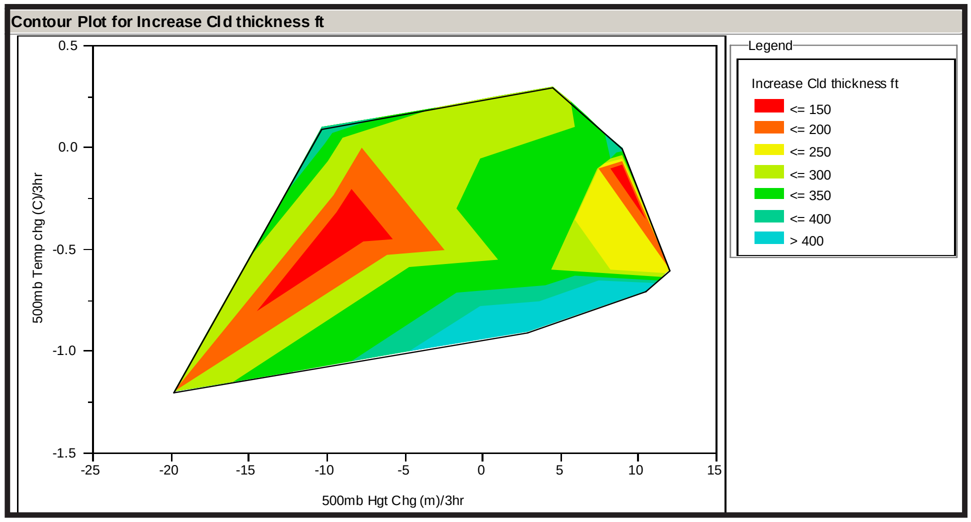

Figure 16. 500-mb Temperature Change/500-mb Height Change/ Increase in Cloud Thickness.

When a weak 500-mb shortwave moved through Vandenberg AFB during the early morning hours on 23 Aug 04 (see Figure 17), atmospheric destabilization increased cloud thickness. It was also observed during the study period that even very weak short waves, only seen in the water vapor imagery, can still affect the cloud dynamics.

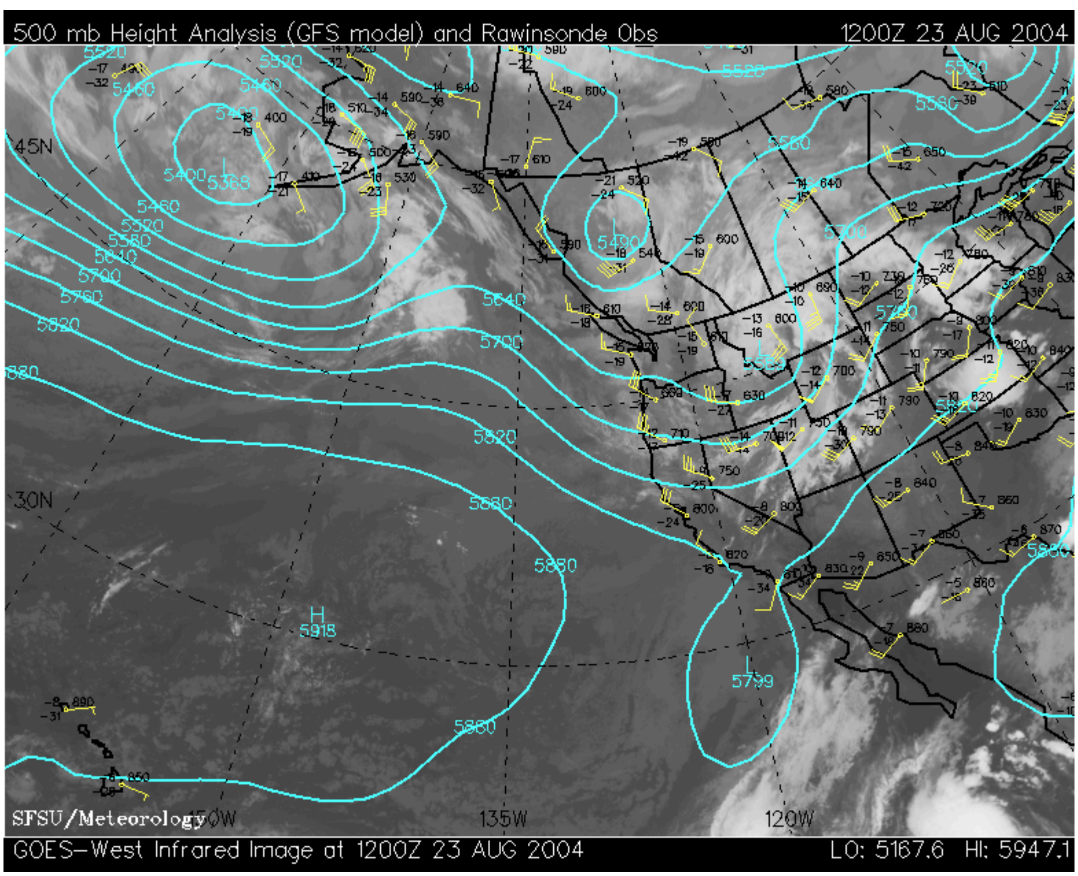

Figure 17. Weak 500-mb Short Wave Moving Through Southern California, 12Z 23 Aug 04.

3.2 How the 500-mb Heights Effect Marine Layer Stratus.

This study refutes the following two Vandenberg rules of thumb: as 500-mb heights decrease the marine layer ceiling will raise, and as 500-mb heights increase the marine layer ceilings will lower.

Figure 18 shows that 500-mb height changes alone do not predicate the ceiling height changes of cloud bases. It is more important to determine whether the area is on the front side of an upper-level ridge axis (downward vertical motion) or the front side of an upper-level trough axis (upward vertical motion). There was no direct correlation between cloud heights and 500-mb height changes.

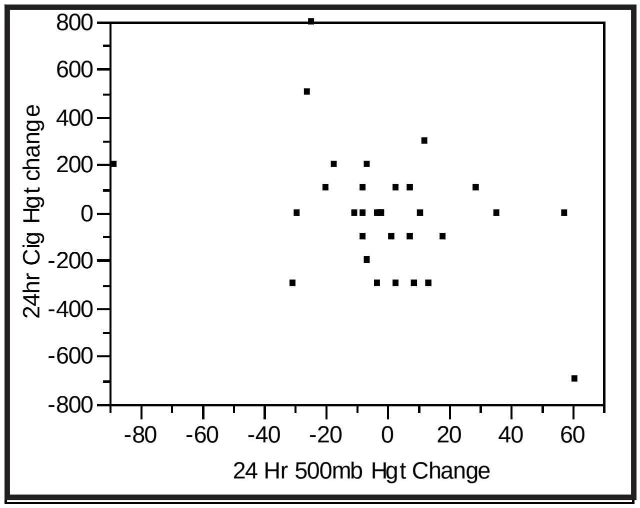

Figure 18. 24-Hour 500-mb Height Changes Compared to the 24-Hour Ceiling Heights Changes.

Table 1 shows the relationship between the 500-mb height change in the previous 12 hours, the 12Z 500-mb height values and the ceilings that occurred at 12Z. "NO" means no ceilings were observed in the combination. Tables 1 & 2 indicate the possibility of developing definitive guidance to determine expected ceilings. They show it is more important to combine the 500-mb height rate of change with the 500-mb height values when forecasting ceilings. The tools we have available to determine the 500-mb height changes and current height values (within 5 meters) are the AWIPS charts (using the sampling feature) and SKEW-Ts. The alphanumeric products only report values in decameters and have less resolution.

During the first half and the last two days of the study period Vandenberg AFB was under the eastern side of the 500-mb ridge, with weak short waves moving through the upper-level pattern. During the middle period the ridge shifted and Vandenberg AFB was on the backside of the upper-level ridge (unstable side). This was important because it affected the height of the subsidence inversion and the downward vertical motion strength. The

Table 1. 12-hour 500-mb height change and height values in relation to ceiling heights.

12hr 500mb	500mb Heights at 1200GMT																						
Hgt Chg	5800	5805	5810	5815	5820	5825	5830	5835	5840	5845	5850	5855	5860	5865	5870	5875	5880	5885	5890	5895	5900	5905	5910	5915
15	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<400	NO	NO	NO	NO	NO	NO	NO
10	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<400	<400	<400	<400	NO	NO	NO	NO	NO	NO
5	NO	NO	NO	NO	NO	NO	NO	NO	NO	<800	<800	<800	<800	<800	<400	<400	<400	<400	<400	NO	NO	NO	NO	NO
0	NO	NO	NO	NO	NO	NO	NO	<800	<900	<600	<200	<200	<400	<400	<400	<400	<400	<400	<200	NO	NO	NO	NO	NO
-5	NO	NO	NO	NO	NO	NO	<800	<800	<800	<400	<200	<200	<200	<400	<400	<400	<400	<400	<200	<200	<200	NO	NO	NO
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-15	NO	NO	NO	>1500	>1500	<900	<800	<900	<400	<200	<200	<200	<400	<400	<400	<400	<400	<200	<200	<200	<200	<200	<400	NO
-20	NO	NO	NO	<1500	>1500	<1100	<900	<1100	<200	<200	<200	<200	<400	<400	<400	<400	<200	<200	<400	<400	<400	<400	<400	<400
-25	NO	NO	NO	<1100	<1500	<1500	<1100	<1500	<800	<400	<400	<400	<400	<400	<400	<200	<200	<200	<200	<200	<400	<400	<400	NO
-30	NO	NO	NO	<800	<1100	<1100	<1500	<1100	<1500	<1100	<900	<600	<600	<600	<600	<400	<200	<200	<200	<200	<400	NO	NO	NO
-35	NO	NO	<400	<600	<900	<900	<1100	<900	<1100	<1100	<900	<900	<900	<800	<800	<600	<400	<200	<200	<200	NO	NO	NO	NO
-40	NO	<600	<200	<400	<400	<800	<900	<800	<900	<900	<800	<800	<800	<800	<800	<400	<200	<200	<200	NO	NO	NO	NO	NO
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-50	NO	<600	<400	<600	<600	<800	<800	<600	<600	<600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
-55	NO	<600	<800	>800	<600	<600	<600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
-60	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 2. 24-hour 500-mb height change (m) and height values (m) in relation to ceiling heights.

24hr 500mb	500mb Heights at 1200GMT																							
Hgt Chg	5800	5805	5810	5815	5820	5825	5830	5835	5840	5845	5850	5855	5860	5865	5870	5875	5880	5885	5890	5895	5900	5905	5910	5915
60	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<600	NO	NO	NO	NO	NO	NO	NO
55	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<600	<600	<400	NO	NO	NO	NO	NO	NO	NO
50	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<600	<600	<400	<400	<400	NO	NO	NO	NO	NO	NO
45	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<800	<600	<400	<400	<400	<400	<400	NO	NO	NO	NO	NO
40	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<800	<600	<600	<400	<400	<400	<200	<200	NO	NO	NO	NO	NO
35	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	<900	<800	<600	<400	<400	<400	<400	<200	<200	<400	NO	NO	NO	NO
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20	NO	NO	NO	NO	NO	NO	NO	<1100	<900	<800	<600	<600	<400	<200	<200	<200	<400	<200	<200	<200	<200	<400	<400	NO
15	NO	NO	NO	NO	NO	NO	<1100	<900	<900	<600	<600	<400	<200	<200	<200	<400	<400	<200	<200	<200	<200	<200	<400	NO
10	NO	NO	NO	NO	NO	<600	<900	<900	<900	<600	<400	<400	<200	<200	<200	<400	<400	<200	<200	<200	<200	<200	<400	<400
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0	NO	NO	NO	<900	<900	<600	<900	<800	<600	<400	<200	<200	<200	<400	<400	<400	<200	<400	<200	<200	<400	<400	NO	NO
-5	NO	NO	NO	<900	<900	<800	<800	<800	<600	<200	<200	<200	<400	<400	<200	<200	<200	<200	<200	<200	<400	<400	NO	NO
-10	NO	NO	NO	<1100	<1100	<900	<800	<600	<400	<200	<200	<200	<400	<400	<400	<400	<200	<200	<200	<200	<400	<200	NO	NO
-15	NO	NO	NO	<1500	<1500	<1100	<800	<600	<400	<200	<200	<200	<400	<400	<400	<400	<200	<200	<200	<200	NO	NO	NO	NO
-20	NO	NO	NO	<1500	>1500	<1500	<900	<1100	<400	<200	<200	<200	<400	<400	<400	<200	<200	<400	<200	<200	NO	NO	NO	NO
-25	NO	NO	NO	>1500	<1500	>1500	<1100	<1100	<900	<900	<400	<200	<400	<200	<200	<400	<400	<200	<200	NO	NO	NO	NO	NO
-30	NO	NO	<900	>1500	>1500	>1500	<1500	<1100	<900	<600	<200	<200	<200	<200	<200	<400	<200	<200	NO	NO	NO	NO	NO	NO
-35	NO	NO	<900	<1500	<1500	<1500	<1100	<900	<800	<200	<200	<200	<200	<200	<200	<200	<200	NO	NO	NO	NO	NO	NO	NO
-40	NO	NO	<200	<1100	<1100	<1100	<900	<900	<200	<200	<200	<200	<200	<200	<200	NO	NO	NO	NO	NO	NO	NO	NO	NO
-45	NO	NO	<200	<1100	<800	<900	<800	<600	<200	<200	<200	<200	<200	<200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
-50	NO	NO	<900	<900	<800	<900	<600	<200	<200	<200	<200	<200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
-55	NO	NO	<900	<900	<800	<600	<200	<200	<200	<200	<200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
-60	NO	<400	<900	<800	<800	<400	<400	<400	<200	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
65	NO	<800	<900	<600	<600	<400	<400	<400	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
70	NO	<900	<800	<400	<400	<400	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
75	NO	<800	<600	<400	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
80	NO	<600	<400	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
85	NO	<400	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
90	<400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
95	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

pattern shifts affected Vandenberg in the following manner:

On 23 Aug, Vandenberg AFB experienced a normal marine layer.

On 30 Aug, a short episode of southerly surge developed (less than 48 hours in duration) northward just past Vandenberg AFB.

During the third shift on 8 Sep 04, Vandenberg AFB was located on the unstable side of the ridge, no marine layer developed.

It is critical to know where Vandenberg AFB is located in relation to the subsidence side compared to the more unstable side of the upper-level ridge. See Figures 19 to 21.

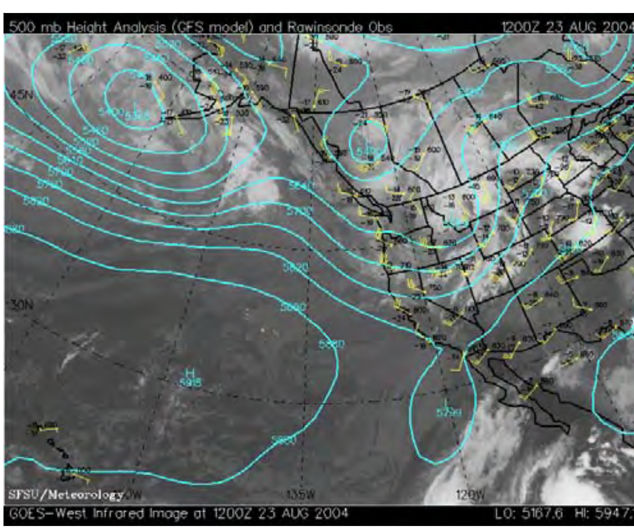

Figure 19. 23 Aug 04 12Z

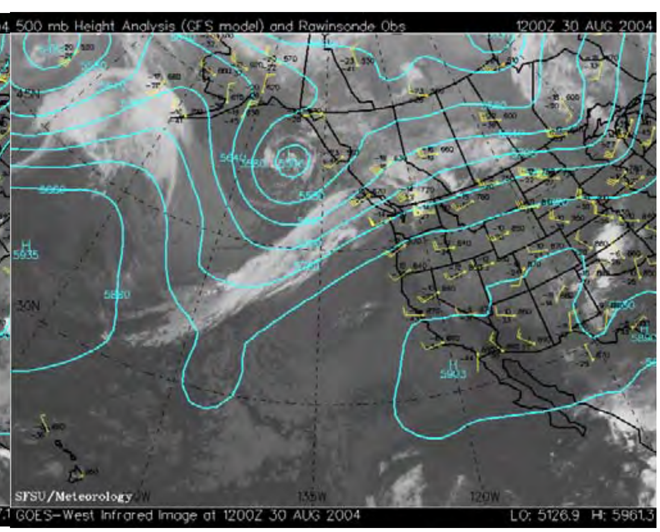

Figure 20. 30 Aug 04 12Z

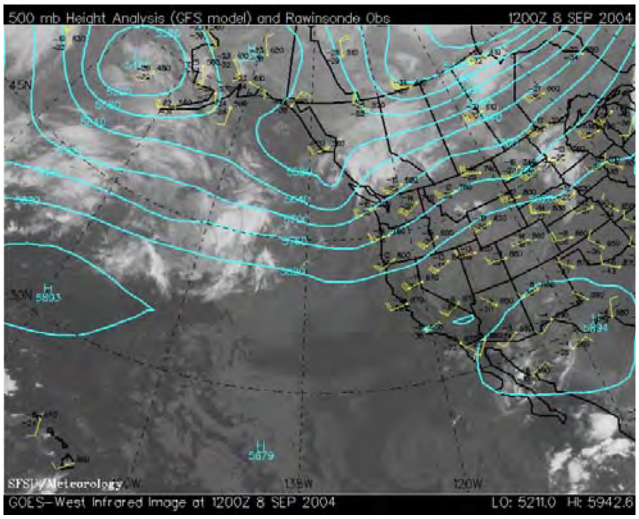

Figure 21. 8 SEP 04 12Z

This supports the conclusion about the relationship between 500mb heights, 500mb temperature and marine layer ceilings.

3.3 Different Cloud Burn-off Rates Occurred at Vandenberg AFB.

Figure 22 shows the burn-off rate averages 320 feet per hour except during southerly stratus surge events and weak short wave passages. During southerly surge events the burn-off rate decreased to an average of 173 feet per hour. Figure 23 compares the 500-mb temperature change and the burn-off rate with shortwave and southerly surge cases removed. There is almost no correlation between -0.3°C to +3°C per 3 hour changes (20 out of 28 cases) and the burn-off rate ranges. This is evidence that some other mechanism is involved.

However, there is some relationship between the 500-mb temperature plus height changes with the burn-off rate (Figure 24). Maximum burn-off rates occurs when the heights increase while temperatures decrease. There is a three-hour delay in the burn-out rate in response to a thermal and contour trough moving through Vandenberg AFB.

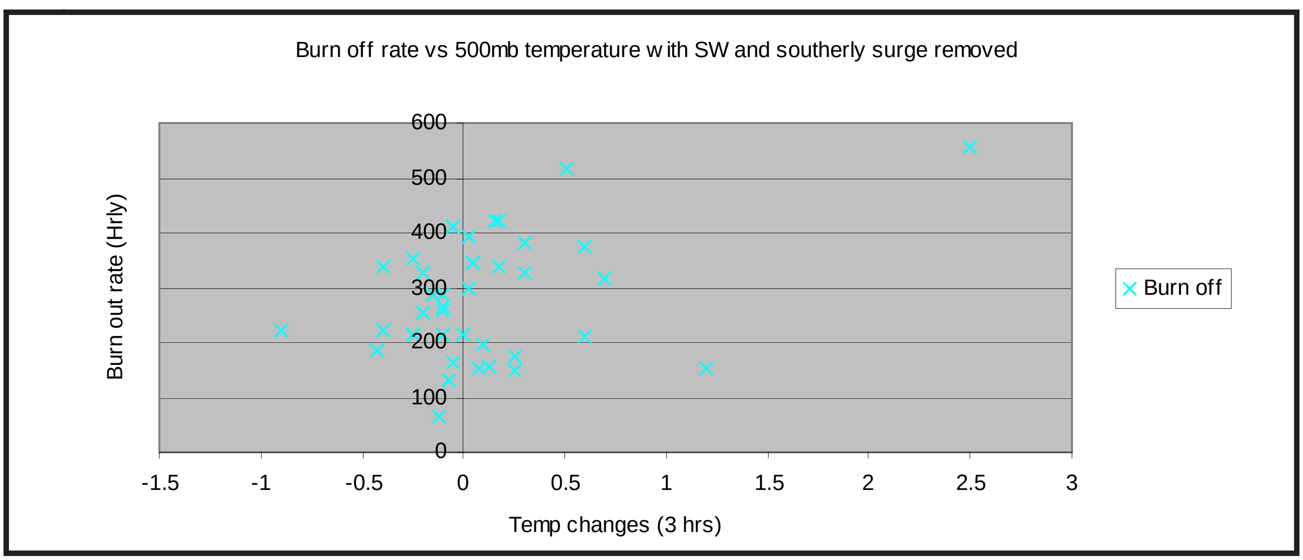

Figure 22. Burn-off Rate Versus 500-mb Temperature Changes without Shortwave Passage and Southerly Surge.

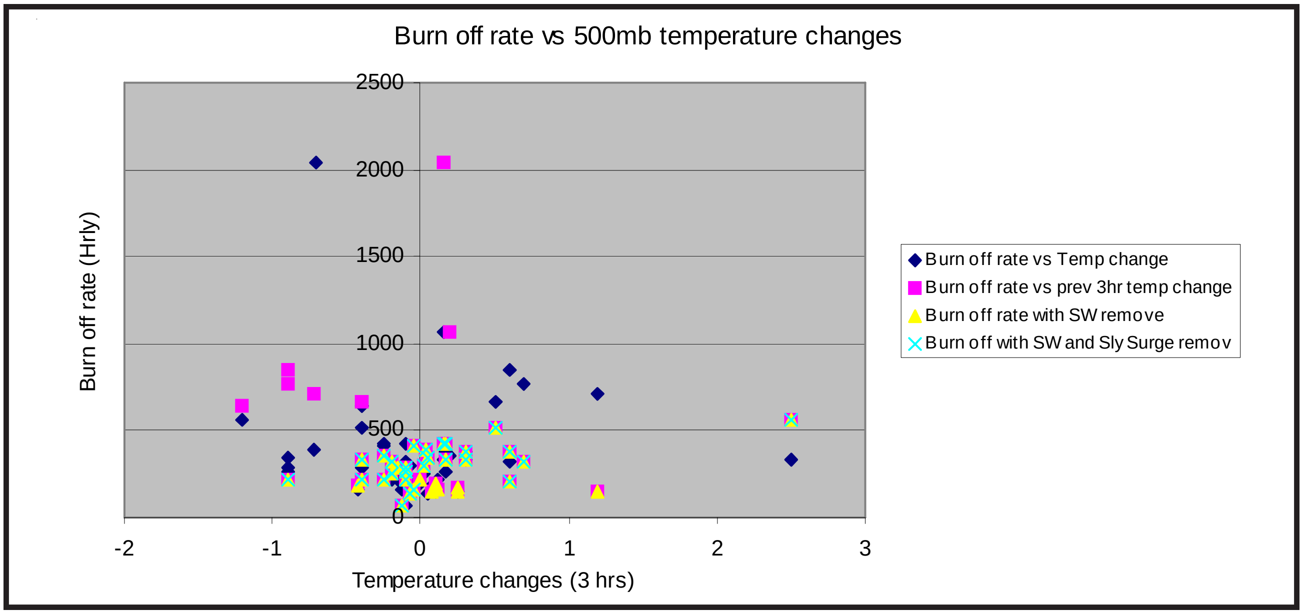

Figure 23. Burn-off Rate Versus 500-mb Temperature Changes.

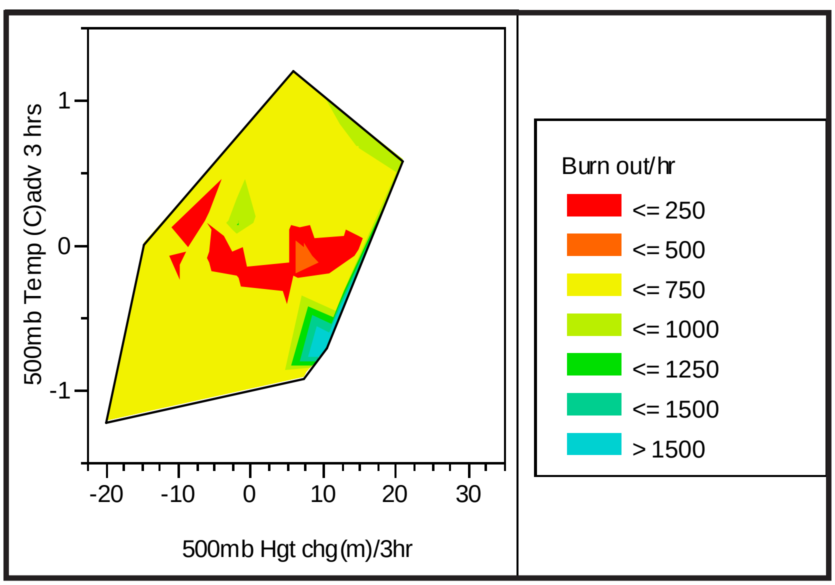

Figure 24. Burn-off Rate Comparing 500-mb Temperature and Height Advection.

3.4 Drizzle—When to Use the 2,000-Foot Thickness or the Dry Entrainment Method.

During the study period, six cases of drizzle occurred. Three cases of drizzle occurred during periods dominated by a southerly surge, while the other three occurred after stratus advected southward from northern California. Figure 25 shows the cloud depths ranged from 1,000 feet to 1,700 feet.

The article written by Paluch and Lenschow[3], *Stratiform Cloud Formation in the Marine Layer*, demonstrates how small baroclinic circulations can set up within the marine layer. They state "an airmass will seek a stable condition such as warm air over colder air."

Cold air over warm air creates an unstable environment. Normally cold air in the boundary layer (below 2,000 feet AGL) infers stable conditions, while warm air infers unstable conditions. Generally for drizzle to develop the clouds must be at least 2,000 feet thick with some type of weak vertical motion. However, in all six cases (Figure 26) the Skew-T cloud thicknesses were observed between 1,000 feet to 1,700 feet (using 88 percent relative humidity as the cut-off for cloud tops) and yet drizzle still occurred at Vandenberg AFB.

Basic mesoscale meteorology for afternoon thunderstorm development is warm air below 600 mb, cold air above 600 mb and dry air entrainment at 700 mb. This provides a mechanism for the air molecules to start moving in the vertical, with sinking cold air replacing the rising warm air.

The same concept works on the microscale level and can be applied within the boundary layer. The 20/12Z Skew-T shows cooler, drier air located immediately above the marine layer. The cooler, drier air is located at 930 mb, where the temperature drops 3°C and the relative humidity drops by 40 percent within 10 mb (approximately 300 feet). The cooler air sinks while warmer air below rises so a small baroclinic circulation developed (cold air entrainment).

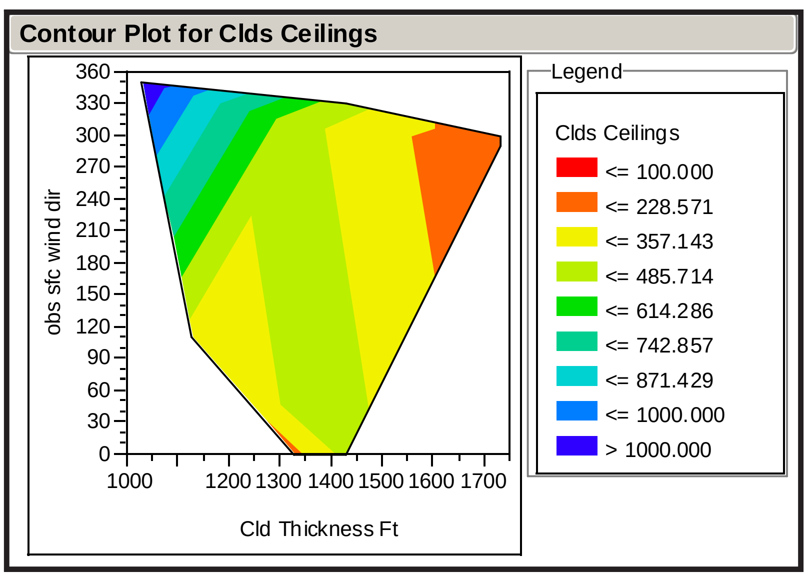

Figure 25. Cloud Thickness Versus Ceiling Heights when Drizzle Occurred.

[3]Paluch, I.R. and D.H. Lenschow, April 1991: Stratiform Cloud Formation in the Marine Boundary Layer, Journal of the Atmospheric Sciences, Vol. 48, No., 19, pages 2141-2158

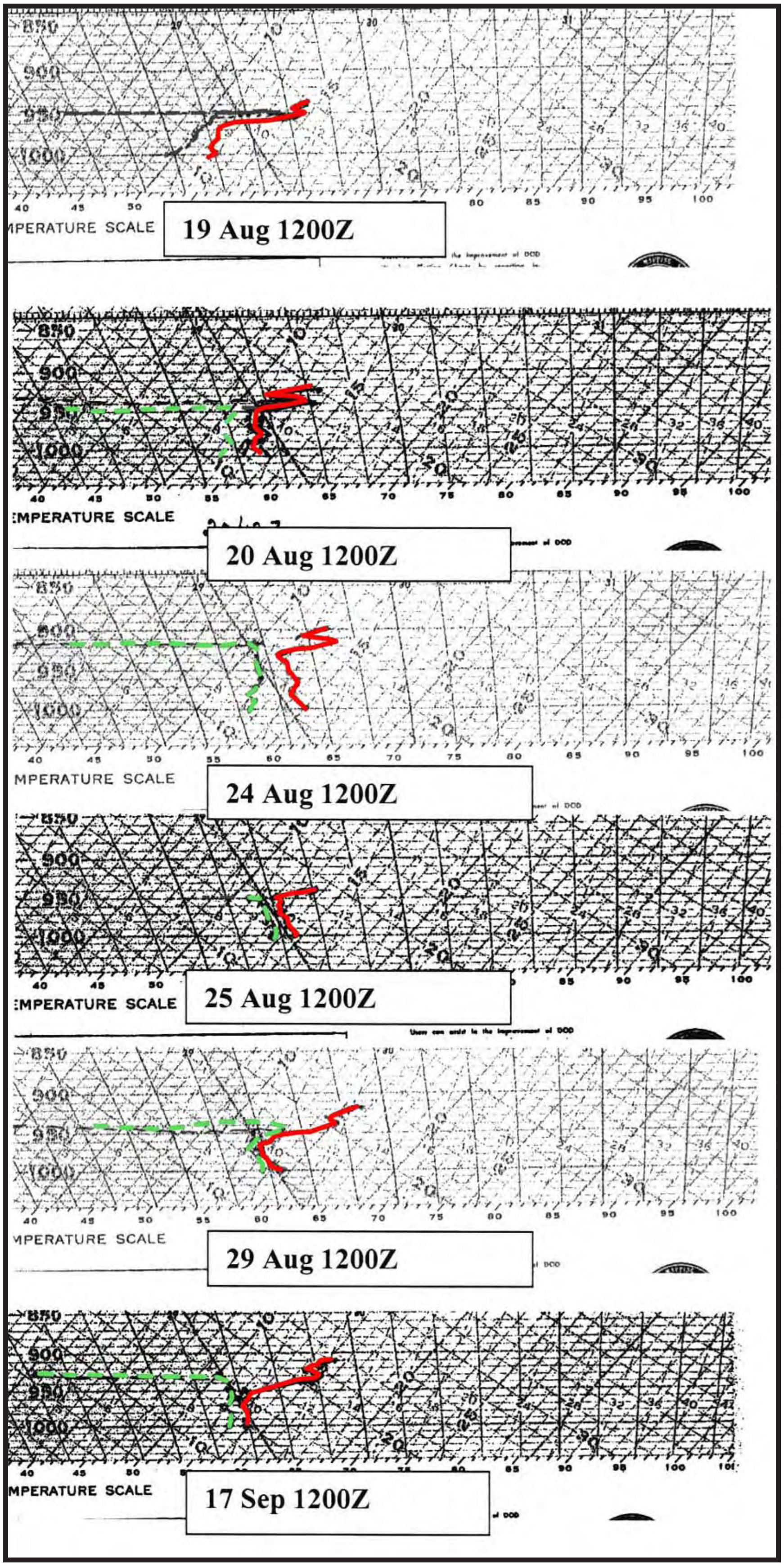

Figure 26. Example of Skew-Ts When Drizzle Was Observed.

Figures 27 and 28 depict the relationship between cloud thickness and cold, dry air entrainment. Drizzle occurred when the value is 1(red area). The rest of the chart depicts when drizzle did not occur. All the drizzle events were associated with cold air entrainment. Figure 27 indicates a trend showing that the thicker the cloud deck, the weaker the cold air entrainment temperature difference needs to be to activate the vertical motion. The reason drizzle may not occur with clouds thicker than 1,400 feet is because the microscale processes are not strong enough for the water droplets to reach the surface.

Referring back to Figure 26, three of the six instances of drizzle occurred when the 925-mb wind flow was predominately southeasterly. Due to radiational cooling, the air just above the higher terrain is allowed to become cooler than the marine layer cloud tops. The cooler air is advected over the marine layer, creating an atmosphere with dry air entrainment. This is most likely how the cooler, drier air is being trapped in the microscale processes. The other three cases developed when a high-pressure ridge moved into Washington and Oregon, providing an easterly flow over northern California and southern Oregon. Clouds then developed off the coast of California and advected southward, reaching Vandenberg AFB within 12 hours of development.

Although it appears to be now casting, the idea of watching the Mini-SODAR's prospective graph (advection processes across the range) may assist in a short-term forecast, in addition to using the temperature on the weather towers located at Oak Mountain (elevation is near 1,400 feet). Additional tools to use to forecast this type of drizzle is cloud top temperatures from infrared satellite pictures using the AWIPS sampling feature.

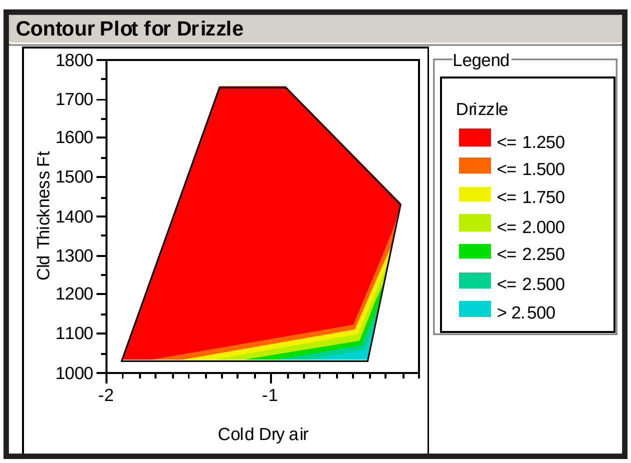

Figure 27. All Occurrences of Drizzle.

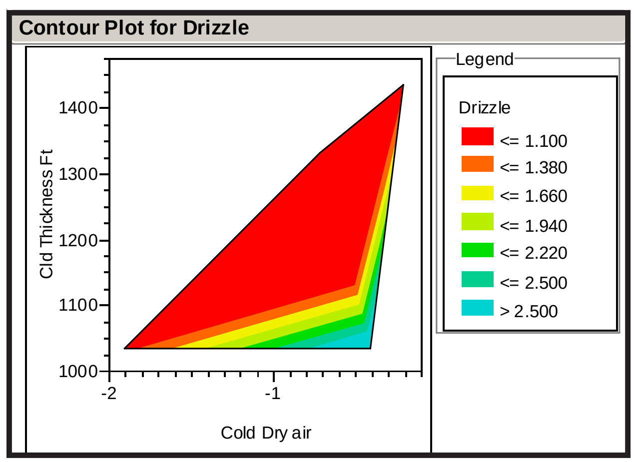

Figure 28. Drizzle without the 1,700-Foot Cloud Thickness and without Southerly Surge.

3.5 Surface Relative Humidity Cannot Be Used to Determine Marine Layer Ceiling Heights at Vandenberg AFB.

As you look at Figures 29 to 31, it becomes evident that no simple correlation exists between surface relative humidity and ceiling heights. The relative humidity values must be influenced by other mechanisms.

Figures 32 to 34 illustrate that during the night the ceilings are routinely rising and falling in a cyclic pattern. Ceilings return or develop around 22Z-23Z and then gradually lower until 02-03Z. They rise a couple hundred feet by 06Z, and then lower again by 200 to 300 feet, with the minimum ceilings being reached during the hours of 12Z to 14Z. The ceilings begin to rise or break out by 17Z. Ceilings above 1,000 feet indicate a similar pattern, except the lowest ceilings occur around 14Z. There is weak dip in the ceiling heights when they are around 1,200 feet, decreasing to 900 feet after 18Z.

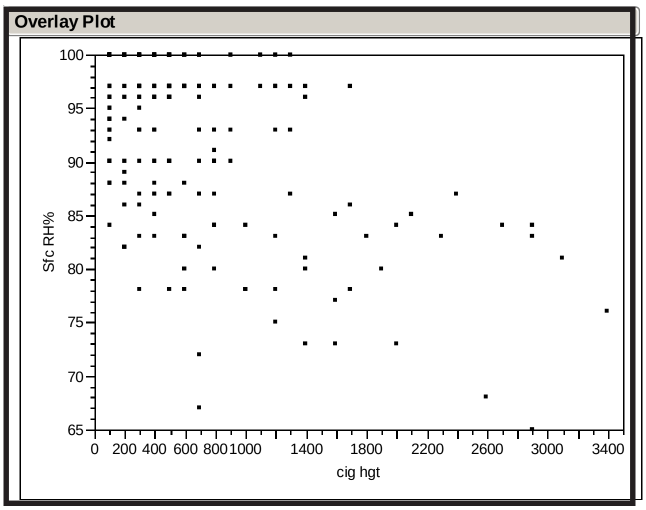

Figure 29. Surface Relative Humidity and Ceiling Heights Using all the Surface Observations.

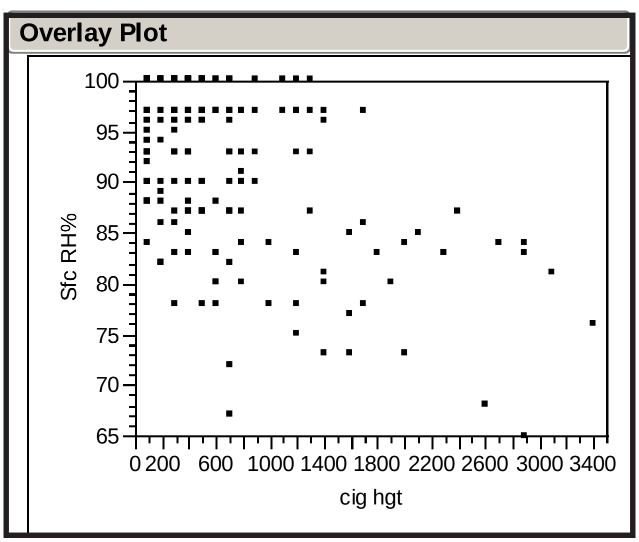

Figure 30. Surface Relative Humidity and Ceiling Heights Using all Surface Observations without Southerly Surge.

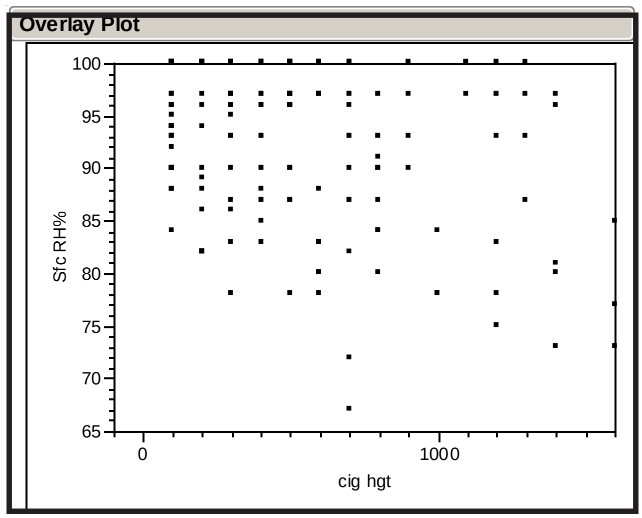

Figure 31. Surface Relative Humidity and Ceiling Heights Using all Surface Observations during a Southerly Surge Only.

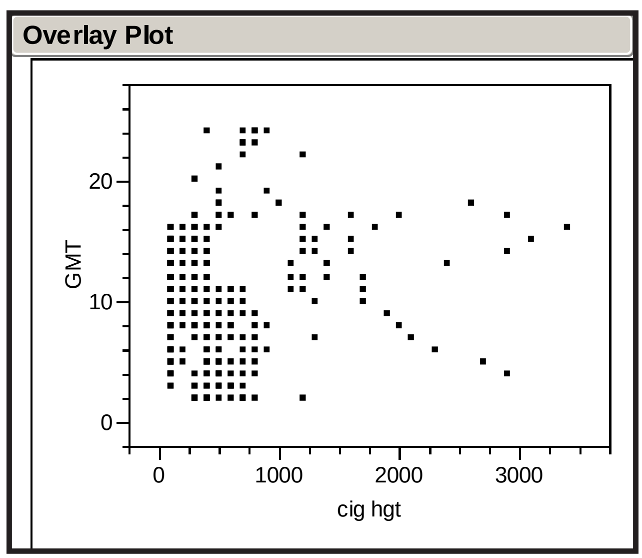

Figure 32. Time Versus Ceiling Height Using all the Surface Observations.

Figures 33 and 34 show a comparison between ceiling heights, surface temperature and time of day. Some correlations are indicated using this comparison. If the surface temperature is between 56ºF to 59ºF the ceilings roll in around 02Z (predominately below 500 feet). A cyclic pattern then drops the ceilings to 100 feet with breakout occurring between 17 to 19Z. If the surface temperature is between 54ºF to 56ºF, the clouds roll in after 08Z at 200 feet. The ceiling slowly increases through the night to 600 feet. It then decreases to 200 feet around 15Z before the ceiling breaks out by 17Z. If the surface temperature is 52ºF to 54ºF then the ceiling quickly breaks by 14Z. When interpreting these figures consider daytime heating and how it affects the break out or ceiling heights. Look at the two figures and compare when the 100-foot ceilings develop. During the southerly surge events, 100-foot ceilings developed with a surface temperature of 60ºF after 15Z, and the ceilings lasted until 17Z. Ceiling heights are predominately 300 feet during the night when temperatures are 60ºF and below.

Figures 35 and 36 show a comparison between ceiling height, wind direction and time of day. It was mentioned in a previous section that there are three basic wind directions that influence the weather pattern at Vandenberg AFB. These two charts will further reinforce that concept. At the top of Figures 35 and 36 wind directions are from 280 to 360 degrees, winds are from the dying sea breeze or gradient flow as the temperature of the land and sea difference decrease. The ceiling

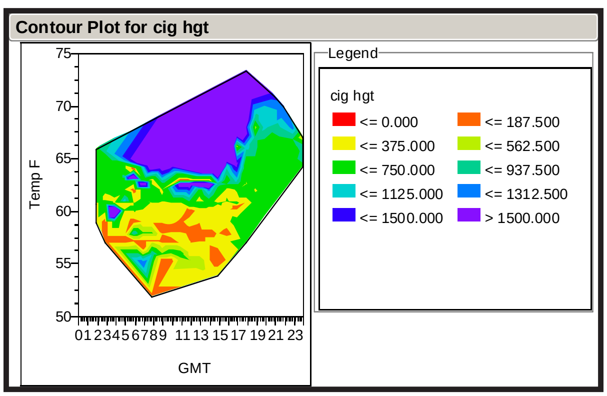

Figure 33. All Surface Ceilings Heights and Surface Temperature Versus Time.

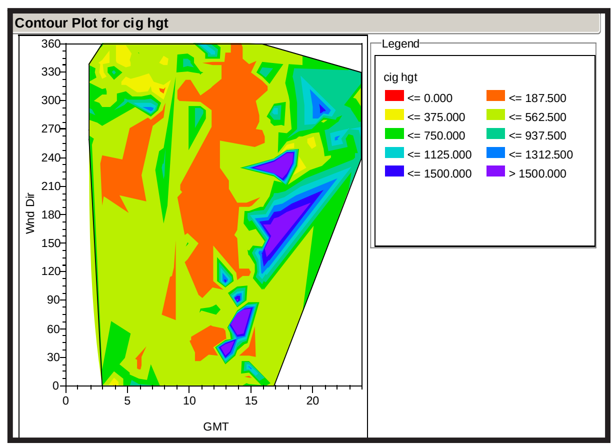

Figure 35. All Surface Ceilings Heights and Direction Versus Time.

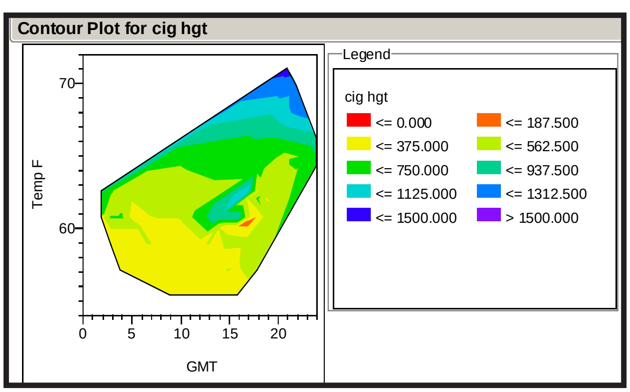

Figure 34. Surface Ceiling Heights Surface Temperature Versus Time during a Southerly Surge.

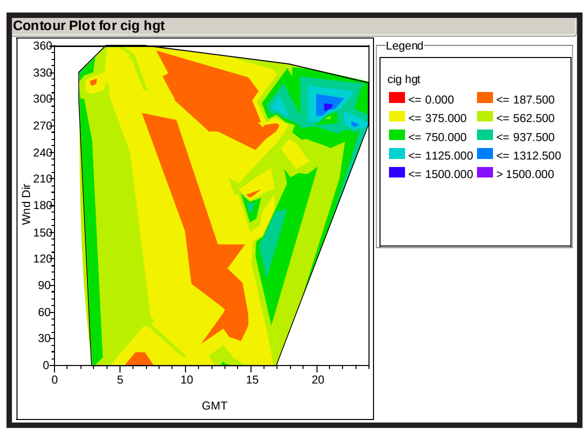

Figure 36. Surface Ceiling Heights during Southerly Surge.

gradually move in at 500 feet and lower, reaching 100 feet after 11Z (remaining until 15Z). When the wind direction is between 200 and 270 degrees, the ceiling decreases to 100 feet after 03Z and then fall under the cyclic pattern mention earlier. When the wind direction is 80 to 190 degrees, the clouds roll in above 500 feet and then decrease to 100 feet by 10Z, increasing after 15Z. When the wind direction was between 360 to 80 degrees, generally due to the surface gradient flow, the clouds roll in around 03Z with ceiling heights around 700 feet and go through the cyclic pattern with short periods of ceilings at 100 feet, finally breaking out between 16Z to 17Z.

During a southerly surge event, there is more of a gradual change in ceilings with respect to wind direction and time. The ceiling will not totally break out if the wind direction is from the west through north. As the wind direction shifts in a clockwise direction, the ceilings delay lowering to less than 200 feet. When the winds are from west to north they go through the cyclic pattern mentioned earlier and rise after 16Z. When the winds are northeast to south, the ceilings increase to around 800 feet then lower back down to 500 feet, with break out around 20Z.

This shows there is no significant correlation between the surface relative humidity values and ceiling heights. A correlation does exist between surface temperatures, winds, time of day and ceiling heights. Therefore, forecasting the surface temperature is important.

4.0 Verification of the Models

The following parameters were compared under all conditions, during a southerly surge event and with the southerly surge data removed: surface temperature, surface relative humidity, surface wind direction and speed, 500-mb temperature and height, 850-mb temperature, and 925-mb temperature. The results of the model comparison indicate that no single model can be used alone to forecast marine layer stratus (see Table 3).

Surface Temperatures. The forecast temperature for all models was too high through the different forecast periods. The best model was the MM5, which was just over 1°C too high at the 07Z and 23Z, and 1°C too low at 15Z.

Surface Relative Humidity. The forecast temperature for all models was too dry, with the MM5 doing the best with an average of 1-3 percent off for all forecast periods.

Surface wind direction. This parameter showed mixed results. The AVN performed the best at the 07Z forecast period, while the MM5 performed the worst. MM5 performed the best for the 15Z forecast period while the Meso ETA performed the best for the 23Z forecast period. The wide direction differences were due to the fact that winds speeds were recorded as calm or forecasted to be calm (created high direction variability).

Surface Wind Speed. The ETA did the best for two out of three forecast periods with wind speed difference of less than 2 knots.

500-mb Temperature. The AVN did the best in this category during all three forecast periods with a mean temperature difference of .13°C

500-mb Heights. The AVN did the best two out of three forecast periods (07 and 15Z), while the MM5 did the best at 23Z. Mean difference was only 3 meters.

925-mb Temperature Difference. During the study period, 925-mb temperatures were not available for the AVN. Local MM5 did very well with a mean difference of +0.02°C while Meso ETA maintained a -2° to -3°C difference.

850-mb Temperature Difference. The AVN was best model two of three forecast periods (07 and 15Z), while Meso Eta did the best at 23Z with a mean difference of only 0.5°C.

4.1. Sourtherly Surge Conditions.

Table 4 shows model verification during southerly surge conditions.

500-mb Heights. The AVN did the best for all three forecast periods with a mean difference of only 1.5 meters.

500-mb Temperature. The AVN did the best for two out of three forecast periods (07 and 15Z) with MM5 doing the best at 23Z. Both models had a mean temperature difference less than 0.41°C

850-mb Temperature Difference. The Meso ETA did well in this category for the 07Z and 15Z forecast periods, with the AVN doing the best at 23Z. Both models had a mean temperature difference of only 0.5°C.

Table 3. Model verification for all conditions. The term “all conditions,” means all the collected data was used for the comparison.

	Mean			Std Dev			Std Err Mean		
All Conditions	07Z	15Z	23Z	07Z	15Z	23Z	07Z	15Z	23Z
500 Temperature Diff									
AVN	-0.1	-0.06	-0.124	0.959	1.223	1.054	0.105	0.133	0.12
Meso ETA	-0.31	-0.31	-0.332	1.266	1.485	1.42	0.121	0.142	0.14
Local MM5	-0.48	-0.3	-0.229	0.881	0.896	0.998	0.108	0.104	0.12
500 Hgt Diff									
AVN	3.069	3.03	4.248	20.092	19.98	21.11	2.205	2.18	2.33
Meso ETA	-11.2	-14.1	-4.242	26.128	29.24	32.53	2.503	2.801	32.5
Local MM5	3.855	8.19	4.09	13.639	12.74	19.09	1.678	1.481	2.24
850mb Temperature Diff									
AVN	0.523	0.49	0.486	1.25	1.186	1.088	0.136	0.129	0.12
Meso ETA	-0.6	-1.11	-0.274	1.931	1.944	2.051	0.184	0.182	0.19
Local MM5	1.051	0.73	0.897	1.296	1.293	1.509	0.157	0.145	0.18
925mb Temperature Diff									
AVN									
Meso ETA	-2.73	-3.02	-2.454	3.684	3.711	3.752	0.35	0.348	0.35
Local MM5	0.219	0.03	0.118	2.61	2.62	2.586	0.317	0.618	0.3
SFC Temperatures Diff									
AVN	-5.21	-4.99	-4.592	10.647	10.67	10.73	0.984	0.958	0.98
Meso ETA	-3.72	-3.05	-3.063	8.583	7.447	9.116	0.548	0.465	0.57
Local MM5	-1.3	1.38	-0.392	6.052	4.988	4.425	0.283	0.219	0.2
SFC RH Diff									
AVN	34.69	33.5	32.03	25.035	24.6	23.51	25.03	24.6	23.5
Meso ETA	12.86	11.9	12.25	21.248	19.42	21.61	1.343	1.235	1.37
Local MM5	3.298	1.16	0.905	15.61	15.01	13.86	0.733	0.656	0.62
SFC Wind Dir Diff									
AVN	-6.41	-30.5	-40.87	152	151.3	141.3	13.82	13.82	12.8
Meso ETA	-18.1	-23.5	-19.29	105.88	104.2	109.3	6.764	6.498	6.83
Local MM5	-18.5	-14.2	-28.23	143.66	91.96	133.7	-1.429	-0.86	-1.7
SFC Wind Spd Diff									
AVN	-2.07	-2.21	-2.623	6.237	5.63	5.596	0.567	0.514	0.51
Meso ETA	-1.33	-1.75	-1.333	4.068	3.823	3.462	0.26	0.238	0.22
Local MM5	-1.43	-0.86	-1.66	3.802	3.065	3.513	0.181	0.135	0.16

925-mb Temperature Difference. During the study period 925mb temperature was not available for the AVN. Local MM5 did very well with a mean temperature difference of -0.68°C to -1.2°C while Meso ETA maintained a negative -3° to -4°C difference.

Surface Temperatures. All the models forecasted temperatures too high through the different forecast periods. The MM5 was the best model and was off by less than 2°C at the three forecast periods.

Surface Relative Humidity: All the models forecasted too dry with the MM5 doing the best with an average of 7% difference for all forecast periods.

Surface Wind Direction. This area showed mixed results. Meso Eta performed the best at the 07Z forecast period, while the AVN performed the best at the 15Z and 23Z forecast periods.

Surface Wind Speed. The MM5 did the best for two out of the three forecast periods with wind speed difference of less than 1.5 knots.

4.2. Without Southerly Surge Conditions.

Table 5 shows the results of model verification without southerly surge conditions.

500-mb Heights. The AVN did the best for two out of three forecast periods (07 and 15Z),

Table 4. Model verification during southerly surge conditions.

	Mean			Std Dev			Std Err Mean		
Southerly Surge	07Z	15Z	23Z	07Z	15Z	23Z	07Z	15Z	23Z
500 Hgt Diff									
AVN	1.59	1.43	0.23	10.47	10.2	13.5	2.402	2.3	3.18
Meso ETA	-17.9	-23	-15	15.88	16	19.3	3.311	3.3	4.03
Local MM5	-5.46	2.02	-4.9	16.86	15.6	22.4	4.353	3.9	5.78
500 Temperature Diff									
AVN	-0.42	-0.2	-0.4	0.983	1.14	1.32	0.225	0.3	0.31
Meso ETA	-1.09	-1.2	-1.1	1.606	1.73	1.7	0.335	0.4	0.36
Local MM5	-0.66	-0.4	-0.4	0.617	0.82	0.86	0.159	0.2	0.22
850mb Temperature Diff									
AVN	0.54	0.7	0.32	1.377	1.6	1.14	0.316	0.4	0.29
Meso ETA	0.43	-0.1	0.91	1.072	1.04	0.82	0.219	0.2	0.17
Local MM5	1.31	1.34	1.29	1.094	0.96	0.96	0.273	0.2	0.26
925mb Temperature Diff									
AVN									
Meso ETA	-4.35	-3.9	-3.6	4.902	4.75	4.13	1.01	1	0.84
Local MM5	-0.68	-1.2	-0.8	3.567	3.54	3.98	0.892	0.9	1.06
SFC Temperatures Diff									
AVN	-6.7	-7.7	-5.8	9.219	9.3	10.1	2.061	2	2.21
Meso ETA	-5.73	-4	-3.6	9.134	7	7.82	1.232	0.9	1.05
Local MM5	-2.76	-1.5	-0.9	3.767	4.1	2.86	0.379	0.4	0.28
SFC RH Diff									
AVN	42.4	40.2	36.2	16.19	16.3	17.5	3.62	3.5	3.82
Meso ETA	15.3	13.7	13.5	19.46	18.5	19.1	2.672	2.4	2.85
Local MM5	7.52	7.4	4.23	8.635	12.2	10	0.868	1.2	0.94
SFC Wind Dir Diff									
AVN	9.09	8.57	-23	154.4	164	144	32.92	36	30.7
Meso ETA	6.6	-24	-25	129.5	124	134	18.9	17	18.1
Local MM5	-19.2	-32	-70	159.4	120	142	16.1	11	13.3
SFC Wind Spd Diff									
AVN	-1.46	-3.8	-2.5	5.449	5.79	3.81	1.162	1.3	0.81
Meso ETA	-1.85	-3	-1.6	3.27	-3	-1.6	0.477	0.4	0.36
Local MM5	-1.03	-1.5	-1.8	2.655	2.5	2.67	0.267	0.2	0.25

with Meso Eta doing the best at 23Z. Both models had a mean height difference of three meters.

500-mb Temperature. The AVN did the best for two out of three forecast periods (07 and 23Z) with Meso Eta doing the best at 15Z. Both models had a mean temperature difference less of than 0.1°C

850-mb Temperature Difference. The AVN took a complete sweep of this category with a mean difference of only 0.5°C.

925-mb Temperature Difference. MM5 took the honors for this category, maintaining less than a 0.5°C difference. During the study period 925-mb temperatures were not available for the AVN.

Surface Temperatures. The forecast temperature for all models was too high through the different forecast periods. The MM5 was the best with a surface temperature difference less than 2°C for all three forecast periods.

Table 5. Model verification for all conditions without the southerly surge.

	Mean			Std Dev			Std Err Mean		
W/O Southerly Surge	07Z	15Z	23Z	07Z	15Z	23Z	07Z	15Z	23Z
500 Hgt Diff									
AVN	3.232	3.2	5	22.33	22.3	23	2.84	2.84	2.92
Meso ETA	-9.37	-12	-1.4	28.05	31.6	34.7	3.03	3.4	3.72
Local MM5	6.596	9.9	6.4	11.34	11.4	17.6	1.59	1.5	2.31
500 Temperature Diff									
AVN	0.013	0.1	-0	0.933	0.86	0.98	0.12	0.11	0.12
Meso ETA	-0.1	0.1	-0.1	1.078	1.33	1.27	0.12	0.14	0.14
Local MM5	-0.43	-0.3	-0.2	0.943	0.92	-0.2	0.13	0.12	0.13
850mb Temperature Diff									
AVN	0.552	0.5	0.5	1.245	1.18	1.08	0.15	0.15	0.14
Meso ETA	-0.88	-1.4	-0.6	2.023	2.04	2.17	0.22	0.22	0.23
Local MM5	0.973	0.6	0.8	1.353	1.33	1.61	0.19	0.17	0.21
925mb Temperature Diff									
AVN	0.552	0.5	0.5	1.244	1.18	1.08	0.15	0.15	1.08
Meso ETA	-2.28	-2.8	-2.1	3.162	3.38	3.6	0.34	0.36	0.38
Local MM5	0.496	0.4	0.3	2.209	2.25	2.12	0.31	0.27	0.28
SFC Temperatures Diff									
AVN	-4.9	-4.4	-4.3	10.94	10.9	10.9	1.11	1.08	1.1
Meso ETA	-3.14	-2.8	-2.9	8.351	7.56	9.45	0.61	0.53	0.67
Local MM5	-0.9	2.2	-0.2	6.49	4.91	4.76	0.34	0.24	0.24
SFC RH Diff									
AVN	33.12	32	31	26.27	25.9	24.6	2.65	2.56	2.56
Meso ETA	12.2	11	12	21.7	20	22.3	1.55	1.41	1.58
Local MM5	2.122	-0.5	-0.1	18.88	15.3	14.7	0.9	0.75	0.75
SFC Wind Dir Diff									
AVN	-9.86	-39	-45	152	148	141	15.3	14.9	14.1
Meso ETA	-24	-23	-18	98.92	98.6	102	7.03	6.94	7.18
Local MM5	-18.3	-9.5	-16	139.1	82.4	129	7.52	4.07	6.58
SFC Wind Spd Diff									
AVN	-2.2	-1.9	-2.6	6.416	5.57	5.93	0.65	0.56	0.59
Meso ETA	-1.2	-1.4	-1.3	4.233	3.97	3.85	0.3	0.28	0.26
Local MM5	-1.54	-0.7	-1.8	4.07	3.16	3.73	0.22	0.16	0.19

Surface Relative Humidity. The forecast temperature for all models was too dry with the MM5 doing the best (an average of 2 percent difference for all forecast periods).

Surface Wind Direction. This area really showed mixed results. The AVN performed the best at the 07Z forecast period, while the MM5 performed the best at the 15Z and 23Z forecast periods.

Surface Wind Speed. The Meso Eta did the best for two out of the three forecast periods with wind speed difference of less than one knot.

4.3 Model Comparison Conclusion

The overall conclusion for the model verification section is that the AVN does consistently better than the mesoscale models when dealing with the atmosphere at 850 mb and above. The MM5 does best with the surface relative humidity, 925-mb temperature and surface wind speed. There is a slight shift in how the models handle situations such as the southerly surge, with reliance on the MM5 for all forecast parameters. The exception to this is the 500-mb level where it is best to use the AVN for guidance.

5.0 Conclusion.

The marine layer behavior is influenced by small upper-air dynamic features in combination with surface features that can often be missed by the forecaster. Marine layer stratus is a feature that occurs entirely below the 925-mb level. As the study indicated, no parameter can be used by itself to determine the marine layer behavior. The forecaster has to keep the mesoscale features in perspective with the microscale processes that are occurring locally. For instance, this study highlights the importance of correctly forecasting the surface temperature, which ties directly to the wind field. This, in turn, controls the low-level convergence and divergence due to the local terrain and the resulting clouds and visibility.

This study resulted in development of decision trees that may assist the forecaster in developing a forecast for the marine layer, temperatures, and winds. Further research is encouraged so weight values can be developed to enhance the decision trees.

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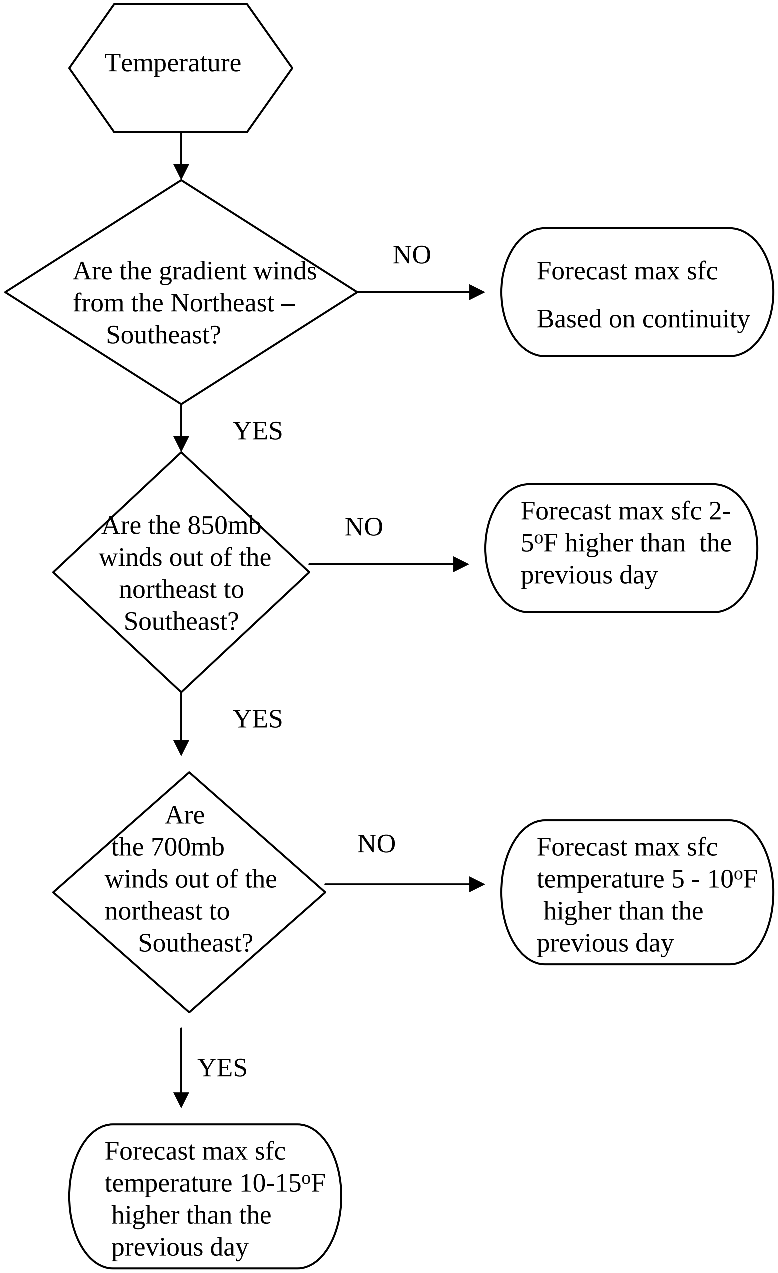
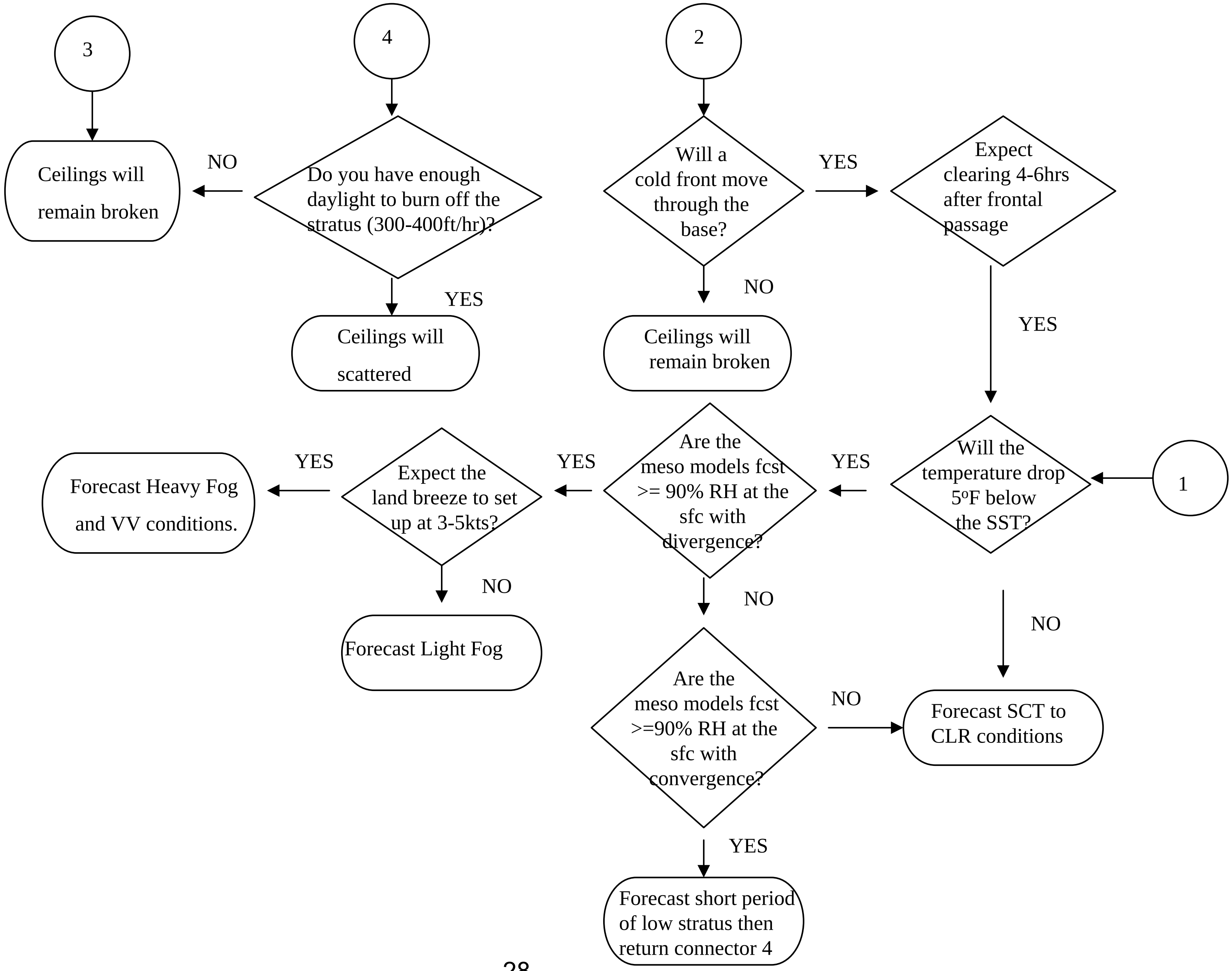
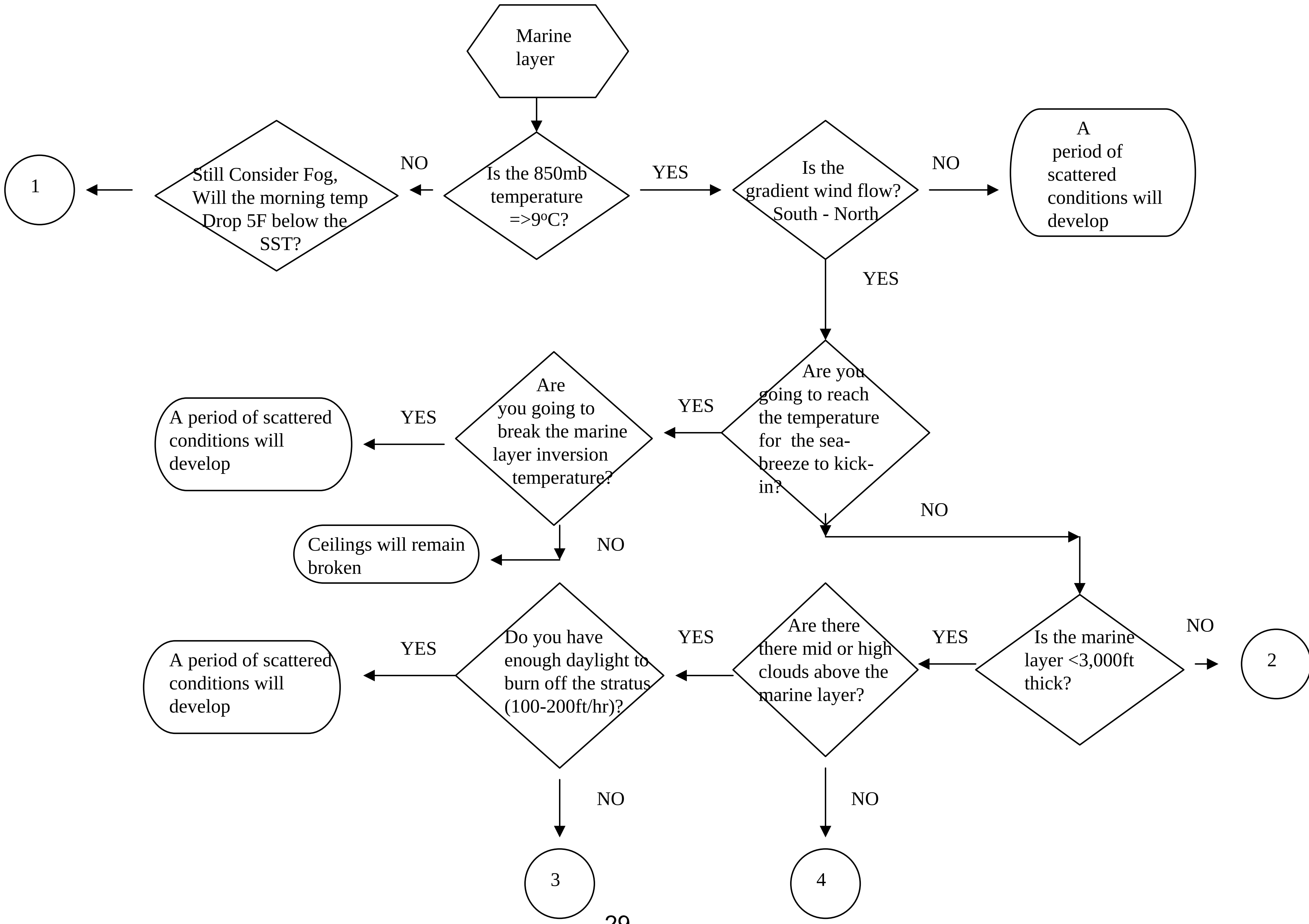
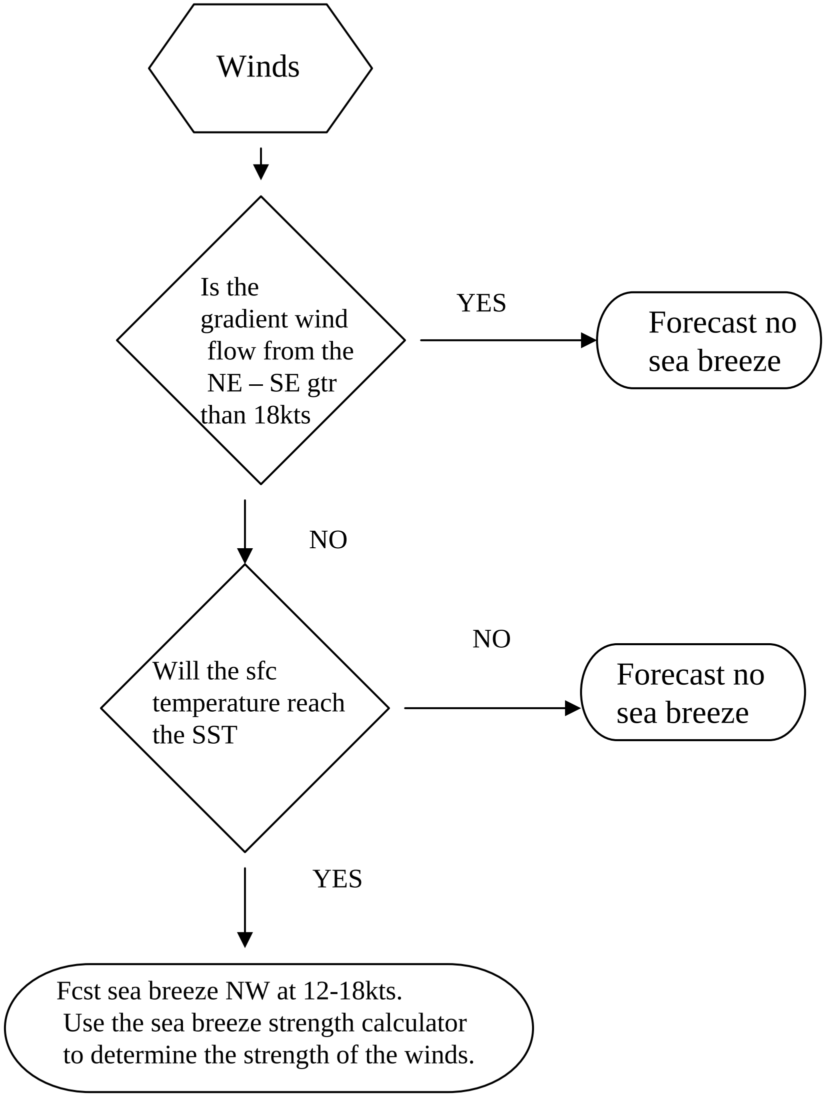

Temperature
Are the gradient winds from the Northeast – Southeast?
NO
Forecast max sfc
Based on continuity
YES
Are the 850mb winds out of the northeast to Southeast?
NO
Forecast max sfc 2-5ºF higher than the previous day
YES
Are the 700mb winds out of the northeast to Southeast?
NO
Forecast max sfc temperature 5 - 10ºF higher than the previous day
YES
Forecast max sfc temperature 10-15ºF higher than the previous day


3
4
2
Ceilings will remain broken
NO
Do you have enough daylight to burn off the stratus (300-400ft/hr)?
Will a cold front move through the base?
YES
Expect clearing 4-6hrs after frontal passage
YES
NO
Ceilings will scattered
Ceilings will remain broken
YES
Forecast Heavy Fog and VV conditions.
YES
Expect the land breeze to set up at 3-5kts?
YES
Are the meso models fcst >= 90% RH at the sfc with divergence?
YES
Will the temperature drop 5°F below the SST?
1
NO
Forecast Light Fog
NO
NO
Are the meso models fcst >=90% RH at the sfc with convergence?
NO
Forecast SCT to CLR conditions
YES
Forecast short period of low stratus then return connector 4



Marine layer
Is the 850mb temperature =>9ºC?
NO
Still Consider Fog, Will the morning temp Drop 5F below the SST?
1
YES
Is the gradient wind flow? South - North
NO
A period of scattered conditions will develop
YES
Are you going to reach the temperature for the sea-breeze to kick-in?
YES
Are you going to break the marine layer inversion temperature?
YES
A period of scattered conditions will develop
NO
Ceilings will remain broken
NO
Is the marine layer <3,000ft thick?
NO
2
YES
Are there there mid or high clouds above the marine layer?
YES
Do you have enough daylight to burn off the stratus (100-200ft/hr)?
YES
A period of scattered conditions will develop
NO
3
NO
4


Winds
Is the gradient wind flow from the NE – SE gtr than 18kts
YES
Forecast no sea breeze
NO
Will the sfc temperature reach the SST
NO
Forecast no sea breeze
YES
Fcst sea breeze NW at 12-18kts. Use the sea breeze strength calculator to determine the strength of the winds.